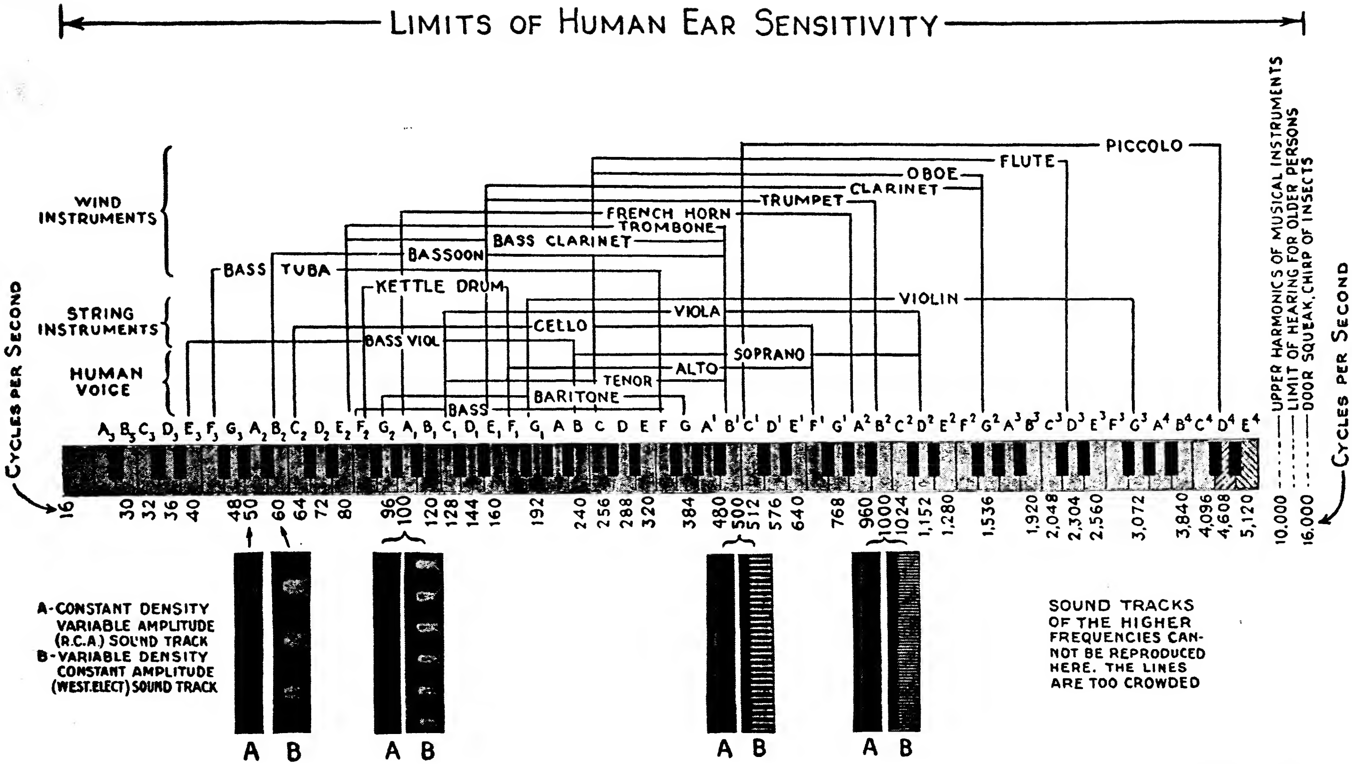
PROJECTING SOUND PICTURES

The quality of the materials used in the manufacture of this book is governed by continued postwar shortages.



(*Frontispiece*)

Chart showing the relationship between the pitch of sound as heard, and the frequencies of the air vibrations of which that sound consists. Showing also the pitch and frequency range of the human voice and of some of the more familiar musical instruments. Indicating, lastly, the relationship between sound frequencies and the appearance of photographic tracks on which those frequencies are recorded.

PROJECTING SOUND PICTURES

A Practical Textbook for Projectionists and Managers

BY AARON NADELL
Publix Theatres Corporation; Formerly of Electrical Research Products, Inc.

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PREFACE

This book has been prepared on a very definite plan, which should be made clear to the reader at the beginning. It is intended primarily for the practical theatre man—the projectionist who is responsible for the operation of sound equipment, and the manager who is responsible for its bills. It aims to present, in everyday English, a practical and commonsense understanding of the "why" behind the operation of sound apparatus.

The book not only very definitely tries to do certain things; it just as definitely tries to avoid doing certain others. For example, electrical phenomena are very largely explained, in these pages, according to the electron theory of the nature of currents. This theory is extremely simple, and absolutely necessary for forming a mental picture of the operation of such parts as tubes and photo-electric cells. On the other hand, it is seldom used in explaining the action of commoner electrical apparatus, so that many projectionists, whose electrical knowledge is otherwise very good, have never heard of it. Therefore it seemed desirable, in dealing with this theory, to begin with its first elements; and as a result the manager who may know very little about electricity and the projectionist who has been working with it for years can start on a more even footing than would otherwise be possible.

Technical terms are used throughout; their meaning is part of the information this book aims to convey. But the reader need not know them to understand the book, or trouble to memorize them as he goes along. Every term is introduced, for the first two or three times, in such context as makes its meaning self-explanatory, and it is believed that the reader who simply reads the book as if it were a novel will acquire a technical vocabulary without conscious effort.

To make this possible, an easy, colloquial style is employed, as unlike the usual textbook style as the author could make it.

It is the principles behind sound results that are dealt with, but they have been most solidly linked with practice, as is fitting in a volume intended for practical men. Thus, while two full chapters are devoted to repairs and precautions, it seemed desirable, in mentioning many principles, to mention at the same time some of the more common troubles (and their cures) involved in the application of those principles. It was felt that by thus intimately tying up theory with detailed procedure in the projection room, the practical value of the book would be increased far beyond any loss that might be suffered through interruption of the flow of narrative.

Every theory dealt with has also been followed by description of some of the more ordinary ways in which it is applied in the construction of practical apparatus. The many pictures used have been carefully chosen for the same purpose—to illustrate the number of very different ways in which some principle, mentioned in the adjoining text, can be applied in equipment, and thus to help the reader to understand its application in the equipment of his own projection room.

Chief among the things the writer has tried to avoid is the practice, heretofore common in books on sound, of attempting to describe in great detail the construction of different types of apparatus. Sound is no longer new, and most projectionists are by this time thoroughly familiar with the constructional details of the installation that is their daily concern. Many of them have developed an almost uncanny knack of remembering any trouble they have had with it, so that they can correct that same trouble at once, no matter how long afterward it reappears. It is just beyond this point, as so many of them have complained to the writer, that the best man cannot go until he knows more of the "background" of his apparatus.

And the manager, whose interest in sound, from the point of view of the budget, is as great as that of the projectionist,

does not care at all about constructional details. He wants an educated ear that will enable him to judge when his sound is right and some understanding of what is wrong with it when it goes wrong. He wants to be able to talk intelligently with the service engineer when expensive changes are recommended. And he feels (as does the projectionist) that everyone will benefit if the two important branches of theatre operation can cooperate with an understanding of each other's problems as well as with mere good-will.

There are some fifty different types of sound systems now in operation, and any book that attempted to give constructional details of all them would be formidable in bulk and in price. Not one page in ten would be of much practical value to the average reader. He would only be confused by details of many strange kinds of apparatus which he has never seen and never will see.

For all these reasons the present volume confines itself to general principles and to an extremely detailed description of how these are applied in practice. It avoids specifying where every nut, bolt and wire is located. It leaves to the individual reader the simple task of securing such information from the manufacturer of his individual equipment—which he can do at no cost to himself. But it lingers over the question of how to use the apparatus—and why—regardless of the appearance or location of the nuts and bolts. The writer believes that this is by far the most valuable information that can be put into any book at the present stage of sound development.

His highest hopes will be realized if the theatrical reader, bearing in mind the aims and necessary limitations of this volume, and merely reading along as much as possible as if it were a novel, finds in it a somewhat clearer understanding of his often exacting job and some little help in his difficulties.

AARON NADELL.

NEW YORK CITY,
July, 1931.

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CHAPTER I

FILM REPRODUCTION

Sound is a vibration in the air, and if we could *see* sound, could stand off to one side and watch it go by, so to speak, we should see that sound is a wave motion. The diaphragm of a loud speaker pushes outward, let us say. Air not being infinitely elastic, all the air in front of that diaphragm cannot get out of the way on such short notice. Consequently, in the region immediately affected, air is compressed, and this area of slightly compressed air travels and spreads in all directions. The diaphragm draws back, leaving an area of comparatively rarified air, which spreads similarly. Plunging forward again, the diaphragm of the speaker starts a new wave of compressed air on its way.

If we could stand off to one side, and watch the sound pass by us, we would see waves of denser air, separated by waves of rarified air, radiating in all directions from the source of sound.

If we stood facing the source of sound, not watching the sound waves pass by us, but letting them hit us in the eye, so to speak, we would see, first, a compression, then a rarefaction of the air, again a compression, again a rarefaction, and so on, continuously.

This is exactly what the photo-cell sees when bands of varying density, photographed onto the sound track, slip downward past the sound aperture.

Crowded Waves: Higher Pitch

Suppose that we are still facing the source of sound and, therefore, the varying densities of the oncoming waves, we should notice two things—provided we could also hear the sound and could identify what was seen with what was heard. We would notice that, as the pitch of the sound grew higher, the waves were shorter and followed one another more rapidly; also, that the loudness of the sound increased directly with the increase in the degree of compression and the corresponding degree of rarefaction. That is, when the compression and following rarefaction

Fig. 1.—Variable-density (Western Electric) sound track. Compare the appearance of this track with the Western Electric recordings shown in the frontispiece. The distinguishing tone of an instrument or voice is conveyed by the supplementary frequencies, or "harmonics" which accompany the pitch frequency, or "fundamental."

were slight, the sound was low in volume; when the volume was strong, the condensation and rarefaction of the air were comparatively great. When the waves followed each other more rapidly—with greater frequency—the pitch of the sound was high; longer waves following each other

more slowly—less frequently per second, at lower frequency—accompanied sounds low in pitch.

If, by some recording device, it is arranged that parallel lines of varying density shall appear on a motion picture film,[1] the width of the lines (that is, the speed, or frequency, with which they follow each other) will correspond to the pitch of sound. The narrower those lines are, the greater the number of lines to the inch of film, the faster they will follow each other and the higher the pitch will be. The density of those lines will correspond to the volume of sound. Very black lines—independent of their width—spaced by very white spaces, will give loud sound. Dim gray lines, spaced by whitish spaces only a trifle less gray, will represent low sound. A film so made constitutes an accurate record of the sounds heard by the recording device.

Trained technicians have been known to read this record; men who have by long practice become familiar with the appearance of words and music photographed into this kind of record can read the words as if they were print, or can identify instruments. If some device could be created that could likewise read this record, and could create "speech currents" of electricity corresponding to it, those currents could be magnified by a vacuum tube amplifier and made to operate a loud speaker.

The Mechanical Reader

The combination of the exciting lamp, optical slit assembly, and photo-electric cell constitutes such a mechanical reader, and creates an electric current corresponding—strength for density, frequency for spacing of the lines—to the sound record on the film.

And this mechanical reader is neither complicated nor mysterious, but almost simple enough to be understood by a child. Simple is hardly the word to describe this combination pick-up device; the photo-cell is the only part of it

[1] The other type of sound track in common use will be discussed later in this chapter.

which involves any principle unfamiliar to a child of ten. And there is nothing difficult about the photo-cell once its principle is understood.

The Photo-electric Cell

The photo-cell operates with electrons, which need not frighten anyone, since all of us have many billions of them in our bodies. In fact, our bodies are constituted almost entirely of them. All the physical matter of the universe is made up, mainly, of electrons. In certain combinations among themselves, they build all the atoms of all material things. Bachelor electrons, free and uncombined, constitute electricity—electric charges, if at rest; electric current, if in motion.

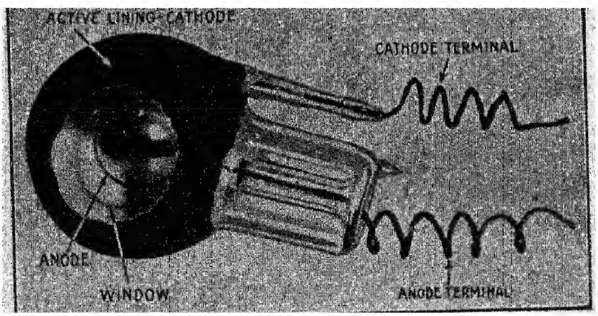

Fig. 2.—Photo-electric cell. (Western Electric 1A type.)

Since the atoms of all material things are made of electrons in combination, it follows that the electron is very much smaller than any atom. Therefore, the atoms of copper wire, for example, offer no appreciable obstacle to the motion of free electrons that want to travel through that wire, constituting a current. A chunk of copper is a "solid" to us; we cannot poke our fingers through it, but it just wide-open spaces to an electron.

On the other hand, for reasons that are still subject to scientific debate, some substances, although no more dense than copper, offer considerable hindrance to electrons

that are bent on seeing the world. Such are glass and rubber, or ordinary air.

Electrons Replace Each Other

Present-day opinion inclines to the belief that a free electron in a copper wire frees a brother electron from the first atom it strikes, itself joining the atomic combination instead. The freed electron moves on to the next atom and repeats the process, the whole relay race proceeding at inconceivable speed. Rubber and air and other insulators do not permit free electrons to "cut in" on their atomic combinations so easily. However this may be, and we may safely leave it to the scientists to argue the point, it is of no importance for understanding the action of the photo-electric cell except in indicating the connection between free electrons and electric currents.

Electrons Leave Home

Some substances have the power of emitting free electrons —discharging them directly into the surrounding air—under the impact of light. Potassium, caesium, and other elements possess this property. Emitted into air, the freed electrons would not go very far, since air is an insulator. But if the potassium or other "active material" is sealed inside an evacuated glass bulb, the electrons emitted can travel comparatively long distances—an inch or so—at extremely high rates of speed.

All photo-cells in common use for sound-on-film today employ this principle.

The sound film has photographed on it varying densities of black and white, which in operation move past a beam of light coming from the exciting lamp and ending on the active material in the photo-cell. The arrangement is such that the light must pass through the film to reach the cell, and the amount of light the cell receives is changed by the changing density of the sound track.

The number of electrons given off by the active material of the photo-cell varies directly with the variations in light striking the active lining. The frequency (rapidity) with which the electronic emission varies is governed by the frequency with which the light varies, and this, in turn, is governed by the breadth of the lines on the film as they slide through the beam of light.

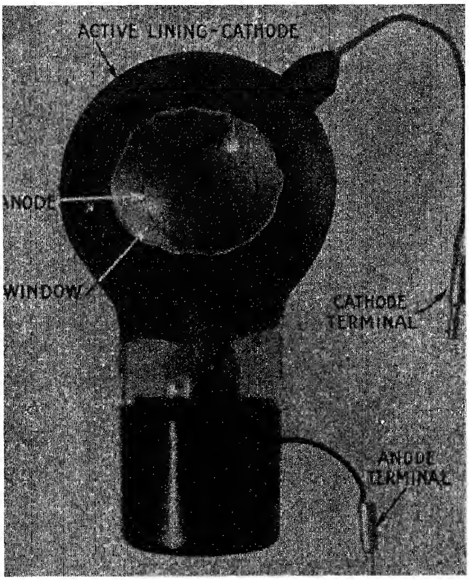

Fig. 3.—Photo-electric cell. (Western Electric 2A type.)

Electrons Are Always Negative

One thing that has not yet been said about free electrons is the most important thing. They are always negative in sign. *Shortage* of electrons in any material constitutes a positive electric charge; *surplus* of them creates a negative charge.

Now the free electrons emitted by the active material of a photo-cell follow this rule; they constitute negative charges, traveling at high rates of speed. The active material they leave behind them is positively charged, or "ionized," by reason of their absence. With no other

outside influence, the electrons would return into the active material as soon as the effects of the light were withdrawn, for opposite charges attract.

The Photo-cell Circuit

But another influence happens to be at work. This is the second element sealed into the tube. An "anode" of copper, or some other conducting material, is placed to catch the runaway electrons. It is charged at 90, or 135, or some similar voltage, by being connected to the positive terminal of a B battery or some other source of potential (depending on the type of system). The negative terminal of the B battery is connected to the active material of the cell.

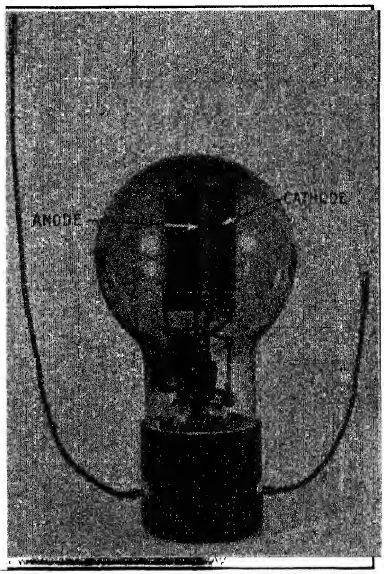

Fig. 4.—Photo-electric cell. (Western Electric 3A type.)

The result is that the free electrons are promptly attracted to the second element of the cell, the anode—*closing the B battery circuit and constituting a flow of current.*

We may state all this another way by saying that under the impact of light the active material "projects a current" through the vacuum of the cell to the anode.

(Incidentally—the fact is of no importance except for understanding the action of such things as photo-cells and vacuum tubes—electric currents happen to travel from negative to positive, and not in the opposite direction. Since all our meters and other devices are polarized in accordance with the old error, it makes no practical difference to think of the thing in either way.)

A transformer or condenser coupling device, introduced in series with the photo-electric cell B circuit, transfers the speech currents set up there to a vacuum tube amplifier, where they are magnified in the usual way and fed into a loud speaker.

The Slit Assembly

Now the beam of light which is interrupted, or "modulated," by the lines on the film representing sound, must be a beam—not a blob. Imagine a line completely black, followed by a space of equal breadth completely white,

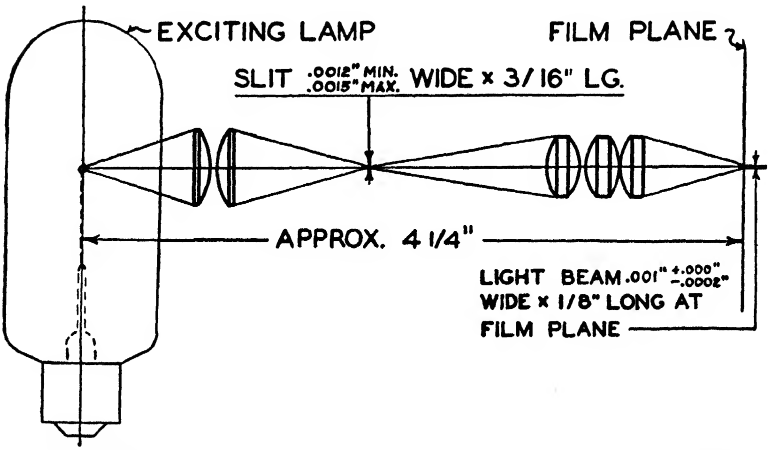

Fig. 5.—Diagram of the action of aperture assembly (slit assembly), Western Electric type, of the light beam focused at film.

representing the maximum volume which can be recorded. When this black line, representing extreme rarefaction of the air, let us say, arrives opposite the light beam, it is intended to cut off *all* light reaching the cell. The succeeding white line, which represents extreme condensation of air, is intended to admit to the photo-cell the maximum light it ever receives. It is obvious then that the black line must be wide enough to block off the light completely. But the width of the recorded lines is controlled by the rapidity with which they must follow each other (the film speed being constant) to secure the desired sound frequency. Therefore, since the width of the line cannot be increased,

the width of the light beam must be reduced to that of the smallest line needed, if maximum change in the illumination of the cell is to be achieved.

Suppose that the exciting lamp is placed in some kind of box, a box with just one slit in the side, and that that slit is 1/1,000 inch high, let us say, and that the sound track is then run down past the slit. Then any black line 1/1,000 inch in breadth would be effective in cutting off all the light; any white line of the same breadth would admit all the light the photo-cell would ever receive under any circumstances. This scheme would work,[1] but it would be very wasteful of light. And, since the exciting light must be so steady that it is often supplied from batteries, wasting light is not good practice. Instead, an "optical slit assembly" is commonly used to focus the exciting light until it is reduced to a beam having the width of the sound track, and a height corresponding to the greatest frequency being reproduced.

Let us see what that frequency may be. The film moves at a speed of 90 feet a minute, which is 1½ feet, or 18 inches, a second. If our narrowest line were an inch broad, we could reproduce 18 changes of light, 18 alternations, or 9 cycles a second. Obviously, if our narrowest line is 1/1,000 inch broad, we can reproduce 9,000 cycles, which is above the limits of present-day amplifiers and speakers. A beam focused to 1½ mils will therefore be satisfactory; focused to 2 mils (1/500 inch), it will be only fair. Nothing higher than 4,500 cycles can be reproduced through a 2-mil slit and that is not quite enough.

Exciting-light Troubles

In order to obtain a beam of this kind it is desirable to have a source of light that is itself a straight line. The exciting lamp, consequently, has its filament arranged to be perfectly straight. If this filament sags with use or is found to slope in a new lamp which has somehow passed factory inspection, another exciting lamp is needed.

[1] It has been used.

Exciting lamps darken with age, due to tungsten vapor condensing on the inside of the glass. If they are so dark that they materially decrease the volume of light, they should be discarded.

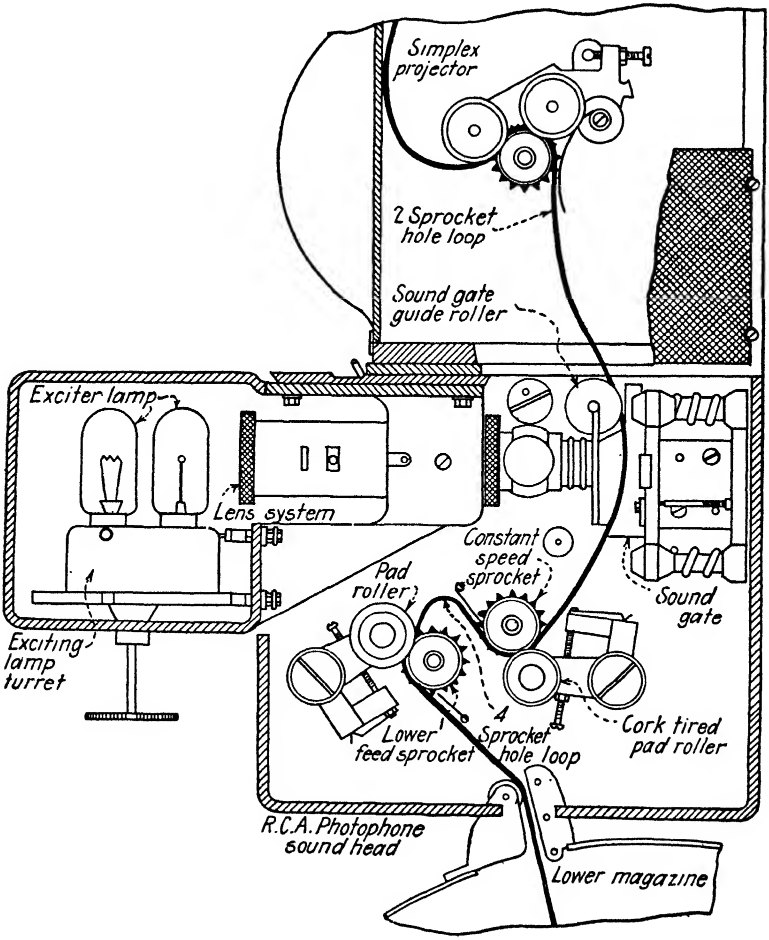

FIG. 6.—RCA-Photophone sound head, type PS-1 for Simplex projector, shows course of film and turret for permitting instant change of exciting lamp.

It is of prime importance that the current supplying the exciting lamp be absolutely steady. The slightest fluctuation of light from this lamp is picked up by the photo-cell and translated into current—hence into noise.

Storage batteries which have run down and are in need of recharging do not deliver smooth current; neither do storage batteries which have been charged, but are in poor condi-

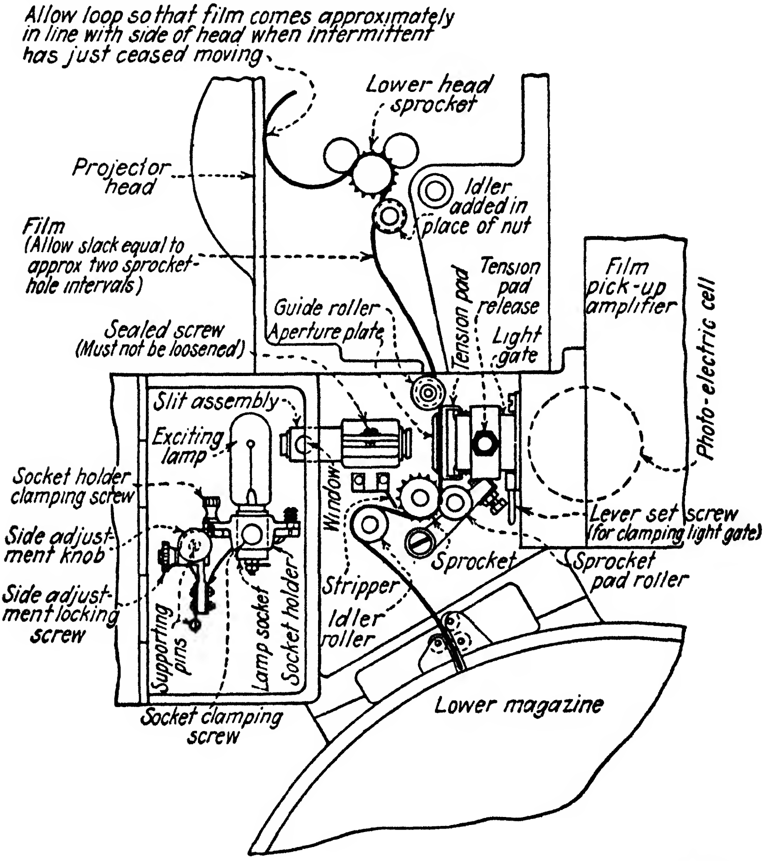

FIG. 7.—Film-reproducing attachment for use with Simplex projector, showing threaded film. (Western Electric Type D 86012.)

tion or old. Here is found one fruitful source of noise in sound-on-film reproduction.

Some systems have several exciting lamps arranged ir a turret, so substitution can be made instantly in case r burns out. Of course, all lamps in the turret must been properly focused in advance. Other system the exciting lamp in a socket which snaps intr

this way, the lamps can be removed and replaced instantly. In such cases a spare socket should be obtained for each projector; a lamp should be fitted in the spare and properly focused, and the spare socket with its lamp should be hung on the front wall of the projection room next to the projector for which it was focused, or otherwise be placed where it can be reached quickly, and where there is no chance of confusion concerning which lamp belongs to which projector. This simple precaution will minimize delays when an exciting lamp burns out.

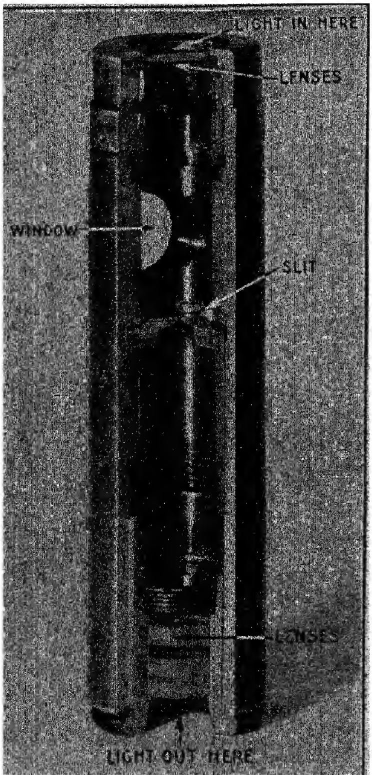

FIG. 8.—Photographic section of Western Electric type aperture assembly, showing window for checking focus on internal slit.

Leaving the lamp, the exciting light is picked up by the focusing device, an arrangement of lenses sealed in a metal tube. The "slit" itself is also sealed in the tube—whence the name "slit assembly." Optical assembly is another name for it, and there are several more. The light entering the assembly is focused on this slit, which gives the beam from that point on its proper shape. Leaving the slit, the beam is refocused so that it will be approximately a mil high when passes through the sound track.

SLIT-ASSEMBLY TROUBLES

mblies cause their own group of troubles. They to be hermetically sealed, but the sealing

is not always perfect. Oil seeps into them, is vaporized by the heat from the lamp, and, consequently, a light comes through that is rather yellowish. Some types of photo-cells happen to work best near the violet end of the spectrum, and with these the effect of oil in the lens assembly is to cut down the volume greatly. Next, the lenses or the internal slits become loose. Because the whole assembly is rigidly mounted to a casting, loose

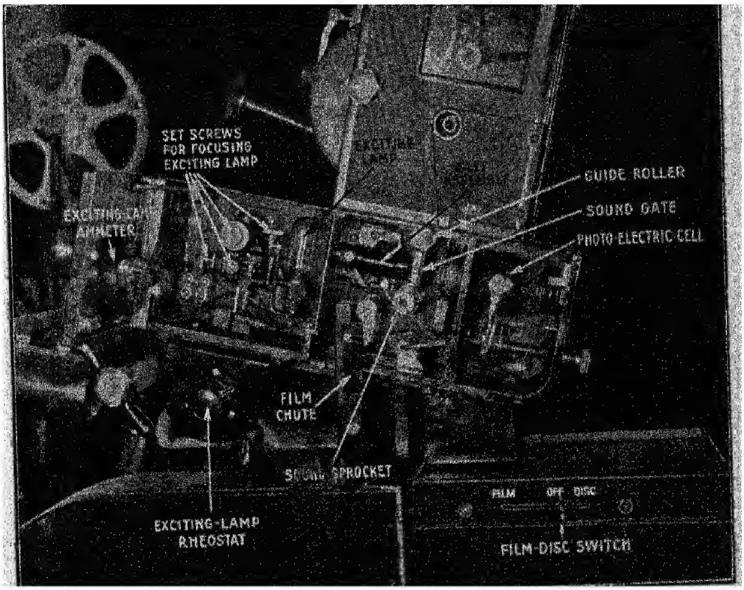

Fig. 9.—Western Electric type 1A sound-on-film attachment, showing compartments for exciting lamp, film, and photo-electric cell. Sound gate shown open for threading. Used only with Universal Base.

lenses or slits pick up the vibration of the projector and modulate the light, that is, vary the quantity of light reaching the photo-cell, in accordance with the machine vibration. Since the current passed by the photo-cell varies with each variation in the light, the variations in light due to projector vibration are added to the variations in light due to the sound track on the film, and the result is that machine noise is added to the sound.

It has been pointed out that the slit assembly is rigidly mounted to the casting of the sound attachment. This is true of both the exciting lamp and the photo-electric cell, as well as the various sprockets and guides that move and control the film. All of these vibrate with the machine

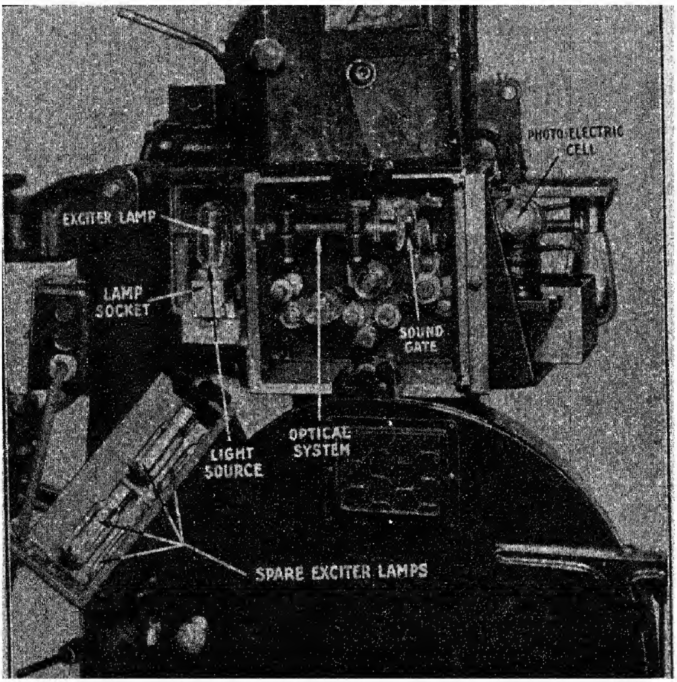

FIG. 10.—Pacent sound-on-film attachment, type for Simplex, showing one-stage photo-electric cell amplifier.

vibration. But since they all partake of the same vibration, relatively to each other they are not vibrating at all; that is, the effect is the same as if they did not, and no harm is done.

Harm creeps in when any one of these coordinated elements vibrates independently. The slits or lenses in the optical assembly may do this, as explained. The exciting lamp may be slightly loose in its socket, or the

socket may be loose in its clips. The anode of a defective photo-cell may be loosely mounted.

The source of such trouble is located quite easily. If the machine is set ready for film reproduction, but no film is threaded up and the motor is not running, tap the several parts gently and listen for the sound at your monitor horn. Various sounds will always be heard, but a comparison with the same test on the other projector will show which ones are abnormal, if experience does not. Tap the exciting lamp and its holder carefully with a finger nail, as you would rap on a door, but much more gently. For the optical assembly, the back of a screw driver may be used, *but it should be used carefully.* Slit assemblies are extremely delicate. Tapping your finger nail against the photo-cell will be more than enough.

Focus Troubles

Tapping the slit assembly may reveal apparent trouble there which is really only bad focusing. This requires a somewhat lengthy explanation. The focus of the exciting lamp is commonly tested by removing the sound "gate." This gate is so called because it is removable; two highly polished metal surfaces on its face press the film against two corresponding, highly polished metal surfaces arranged opposite; this combination of apparatus constitutes what may be called the "sound aperture."

Its purpose is to hold the film firmly, so it cannot move or flap toward or away from the photo-electric cell, and to hold it in focus, so that the light beam will be narrowest where it passes through the sound track.

The gate being removed, a card or piece of paper is generally held in the space vacated, as close to the photo-cell as possible—with no film in the machine. The beam of light, which, where it crosses the sound track, is only about a mil high and not much wider than the sound track itself, will here have grown to a clear-cut oval the size of a hazel nut or thereabouts. That is, the oval of light thrown against the card is clear-cut, and is entirely of an even illumi-

nation and color, if the focus is correct. If the focus is not correct, it is improved by shifting the setting of the exciting lamp by means of the adjustments provided for that purpose.

There Is a Double Focus

But the focus may appear clear on the card, and still be badly enough off in reality to cause noise. Within the slit assembly the light is focused on a tiny slit, which shapes the beam from that point on. Many, although not all, such slit assemblies have little windows in the side of the brass tube, through which the spot of light impinging upon the slit can be seen. Look through this, using tinted glass, or a gelatine from the stereoptican, so that you can see plainly. It may happen that the focus is such that the upper or the lower portion of the spot of light, rather than its very center, is crossed by the slit. In that case, even though the card held in front of the photo-cell shows a perfect oval—perfect focus—noise will follow when the assembly is tapped gently with the butt of a screw driver. In this condition the intensity of light, apparently uniform to the human eye, actually shades off sharply; the slightest motion of the slit, relative to the exciting-lamp filament, a motion so small as to have no effect under proper conditions, changes the value of the light striking the slit, and hence the amount passing through it to reach, eventually, the photo-cell.

If your slit assembly has no viewing window, you can adjust the internal focus while the machine is running without film, listening to the monitor until that adjustment which gives minimum noise is obtained.

Be Careful with Slits

In some sound systems loose slits, or loose lenses in this assembly, are beyond ordinary projection room repair. A new assembly should be installed when necessary, and the old one returned to the maker for adjustment. The same

applies to an assembly which gives a yellow light because oil has seeped into it. In the product of other manufacturers, projection room repair is possible.

The outside of the lenses at each end of the assembly should frequently be wiped clean, both to secure maximum volume by preventing obstruction of the light and to clear away light particles of dirt that might tend to vibrate when the machine is in motion, and so cause noise.

After passing through the film, altered in quantity—or modulated—by the markings on the sound track, the exciting light enters the photo-electric cell on the last stage of its journey.

The Photo-cell

The photo-cell may be held in a clamp, or it may have a base like the base of a vacuum tube and fit in a vacuum tube socket. In the latter case the base of the cell will have four prongs to hold it firmly in the socket, but only two of these prongs will serve as conductors. One connects to the anode, which is the positive element located in the center of the cell and designed to catch electrons emitted by the active material. The other conductor connects to the other pole of the cell—the active material which emits electrons under the impact of light.

The active material often—but not always—is applied to the inside of the glass. As a result, the bulb, when looked at from the outside, usually has a silvered, mirror-like appearance. But light must reach the interior of the cell, so that electrons may be emitted from the inside of the active lining and reach the anode across the vacuum. To effect this the entire surface of the glass is not coated; a small portion is left clear to serve as a "window." Seen through the window the active material in most cells has a shimmering, mother-of-pearl appearance.

The active lining of most photo-cells happens to liquify at rather low temperatures. Often when this occurs tiny drops fall off the glass, leaving pinholes that can be seen by holding the cell up to a light and peering through

the window. The consequent loss of a portion of the active material results in a corresponding loss of electronic emission and, hence, of volume. The difference grows noticeable when the pinholes become very numerous. For this reason great care should be taken not to store spare cells of this type in any exceptionally warm place. In summer or in warm localities only the minimum number of "spares" should be stocked, in order to prevent loss from deterioration of cells while on the shelf.

How the Photo-cell Works

The exciting light, having been duly modulated by the moving film, enters the cell through the window and impinges upon the "active material." Electrons are emitted from that material accordingly, in amounts governed by the amount of light which caused the emission. Or, we may say, "a current is projected from the active material," the strength of this current being proportional to the intensity of the light that created it. When the light changes in quantity, the emission, or strength of the photo-cell current, changes in quantity likewise. The action of the emission and of the passage of the electrons across the vacuum to the anode is fully fast enough to take care of the most rapid changes in light intensity ever encountered at voice frequencies.

Of course, the current crossing the vacuum of the cell is not created there; it is created in the B battery, or other source of power, which polarizes the cell. The *amount* of current flowing in the B photo-cell circuit, as said before, is controlled by the amount of light striking the cell; more light means more electrons emitted which, in turn, means more current; less light means less electrons, and, therefore, less current. The greater the variation in current value, *i.e.*, the greater the amplitude of the swing between minimum and maximum current, the louder the sound. The smaller the difference between minimum and maximum current, the lower the sound. That is, the volume of sound varies directly with the degree of modulation of the light,

which is the same, exactly, as the degree of modulation of the B battery current. The pitch of the sound varies with the frequency of the modulation of the current, which is the

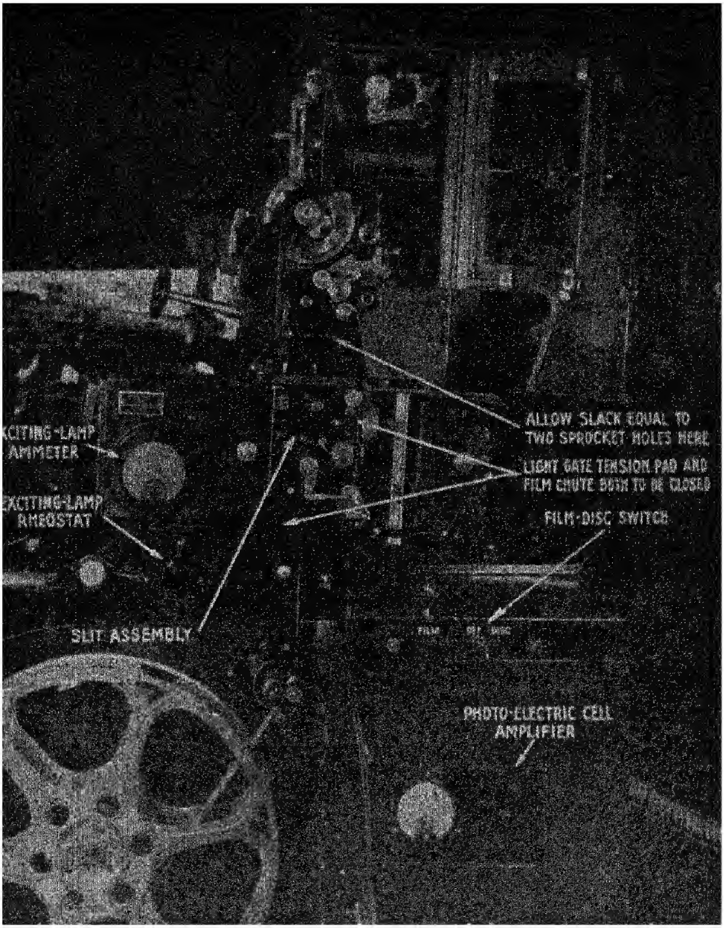

FIG. 11.—Photograph of Western Electric 1A type sound-on-film attachment, showing film threaded up in attachment and in Simplex projector.

same as the frequency of modulation of the light, which, again, is the same as the frequency with which light and dark lines slide through the 1-mil portion of the exciting-lamp beam, and this frequency depends, since the speed

of the film remains constant at 90 feet per minute, upon the thickness, or height, of the lines.

The Polarizing Potential

It will be remembered that a positive polarizing potential of fairly high value, such as 90 or 135 volts, is necessary

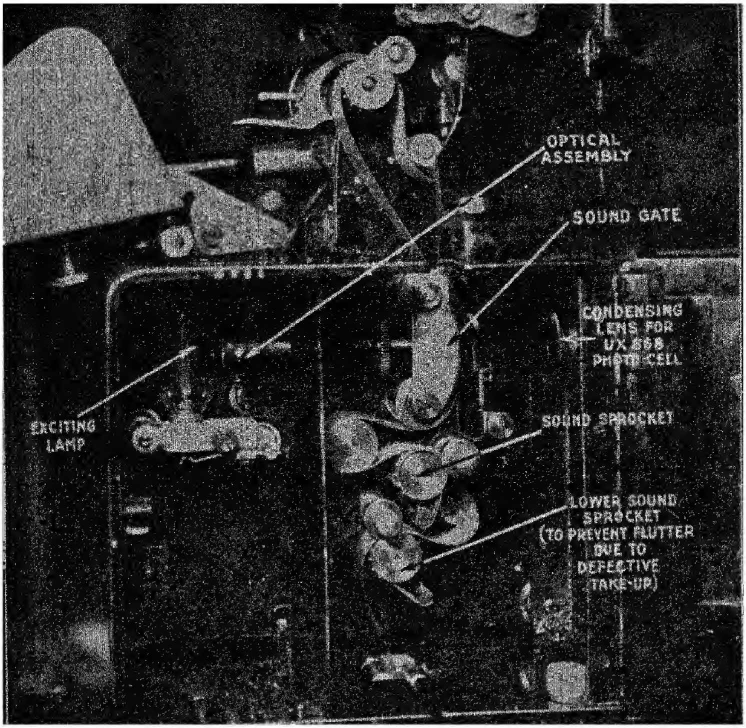

Fig. 12.—RCA-Photophone PS-14 sound-on-film attachment, showing course of film.

across the cell, if it is to function. The electrons (which are always negative in sign) are attracted to the anode, and so cause a flow of current across the vacuum to the anode. If this potential is destroyed, no current will flow across the cell, regardless of the fact that the light is still inducing emission of negative electrons from the active

material. Without the anode to attract these electrons and carry them away, there is emission but no current flow. In other words, the circuit is not closed. As soon as the light is withdrawn, the electrons will return to the active lining, which is left positive by reason of their departure. But with

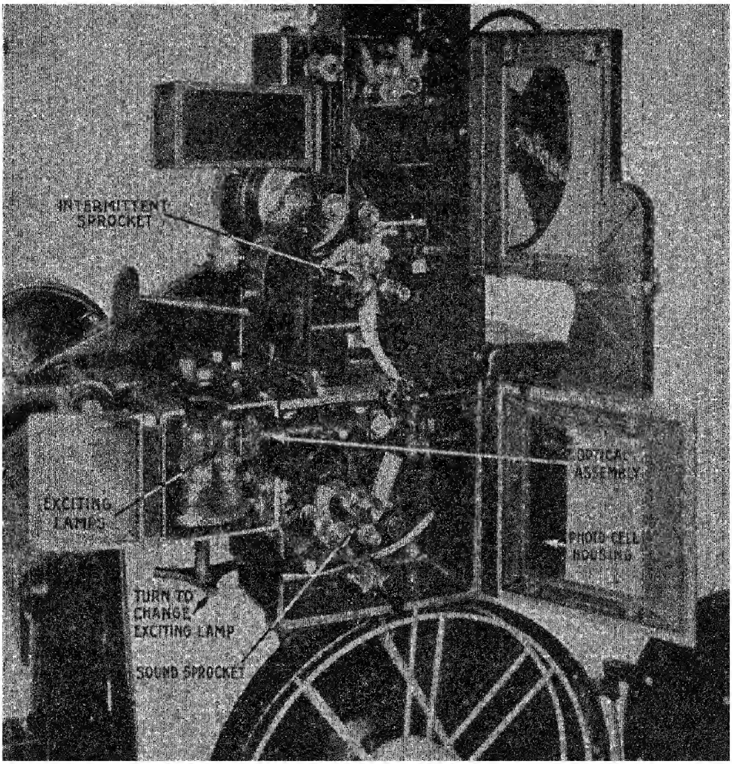

FIG. 13.—RCA-Photophone type PS-1 sound-on-film attachment, showing course of film in attachment and in Simplex projector.

the battery connected the anode sweeps them away and new electrons come up into the active material from the negative pole of the battery.

B BATTERY TROUBLES

The current flowing across the photo-cell should vary only according to the variations in the light entering that

cell. If the B battery, or other source of polarizing power, gives the anode an unsteady voltage, the current will reflect this unsteadiness just as faithfully as it reflects variations of light. Therefore, only the very best and most trustworthy B batteries should be used in this circuit; and for the same reason any generator or rectifier used

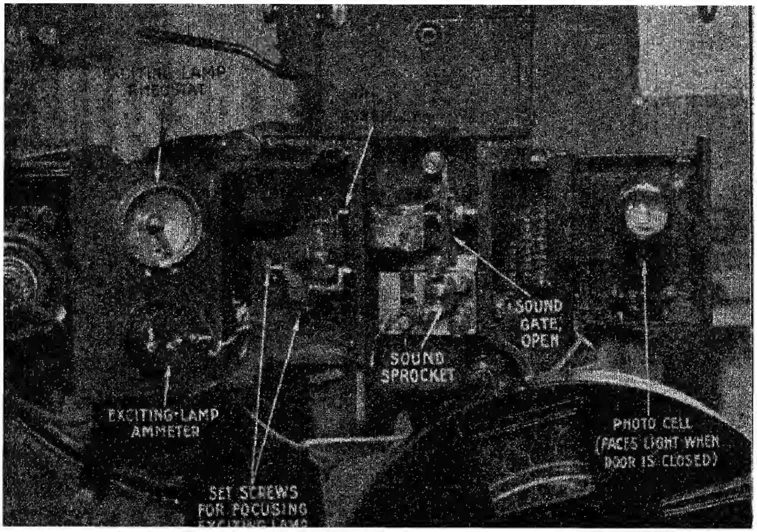

FIG. 14.—Royal Amplitone sound-on-film attachment, type for Simplex.

for this purpose must, with its filters, be in the very best of condition.

Frying B batteries are a common cause of noise; a very annoying one, too, since they sometimes become quiet just when one is checking into that particular question and become noisy again as soon as the trouble is sought elsewhere. It does not pay to take chances with them. By the same token, it does not pay to keep many spares. The current drain is so small that to a large extent these batteries die of their own internal action, and their useful life is practically the same as their shelf life. For this reason if two are bought at the same time, and one is kept as a spare, the spare is likely to become noisy about the

same time that the one in use does. It is best to rely on a local radio dealer; care should be taken to purchase a reliable make, and a battery that is fresh from the factory.

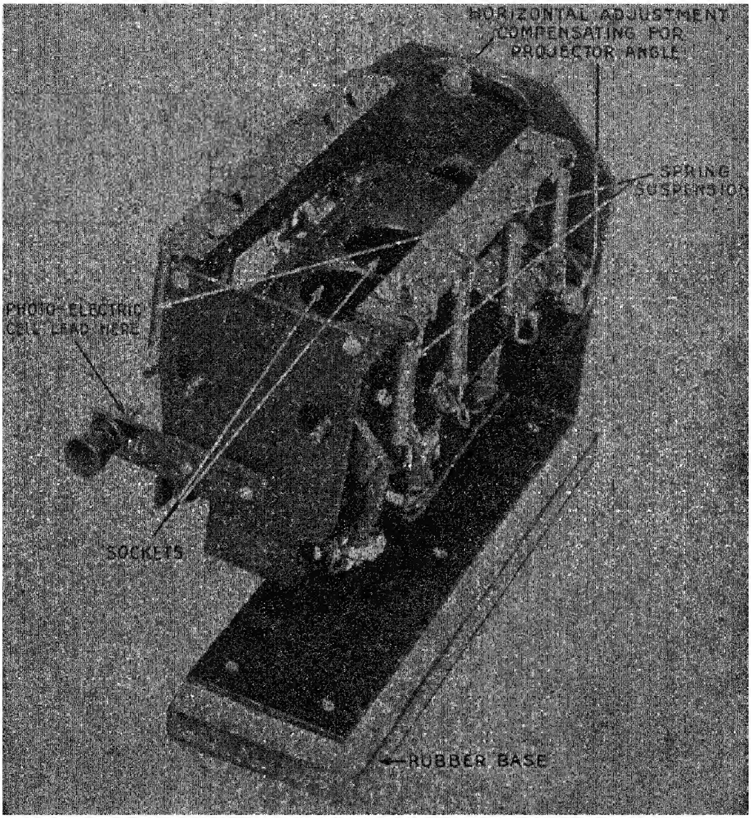

Fig. 15.—Western Electric, type D 86729 photo-electric cell amplifier, showing rubber base, cradle slots, and holding screws for adjusting to projector angle.

Photo-cell Coupling

Frequently the photo-cell has an output so low that it is coupled, with a "resistance capacitative coupling," to a special amplifier mounted only a few inches away on the same projector. The current in such cells is so low that it cannot be transferred without great distortion and, possibly, complete loss, to the main amplifier rack a few

feet distant. The size of the connecting wire has nothing to do with this; the losses and distortion are due to capacitance effects which will be explained hereafter, and not to straight resistance. Other cells, such as those of the Radio Corpora-

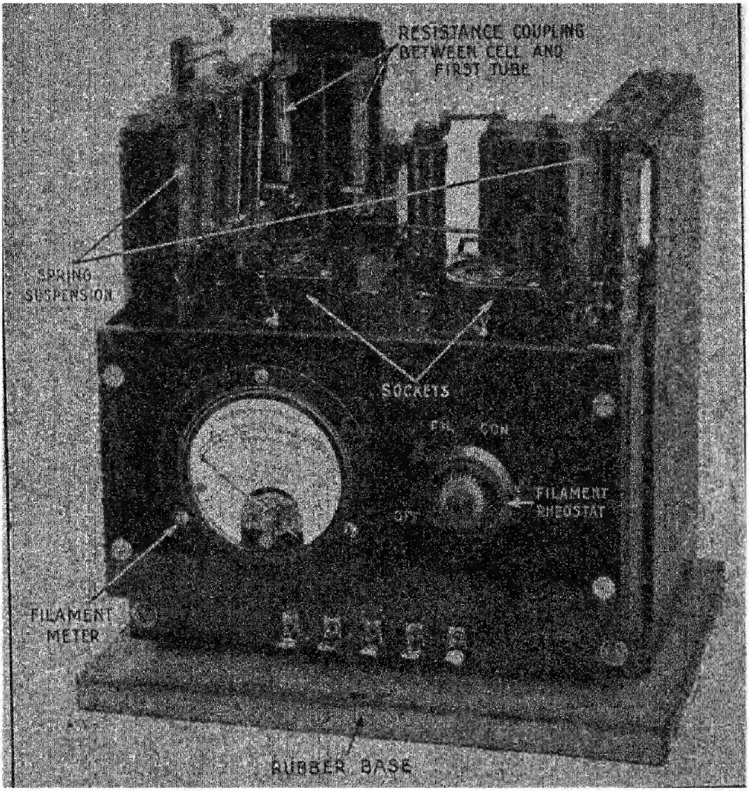

FIG. 16.—Western Electric type 49A photo-electric cell amplifier.

tion, have enough output, especially when transformer-coupled, to feed directly into the main amplifier. In the case of cells which have a special amplifier mounted on the projector, this amplifier is for the photo-cell output only, and is not used to amplify the product of the disc reproducer.

SAW-TOOTH SOUND TRACK

But we have not yet considered the other type of film sound track in common use, the one which does not have

parallel lines of varying densities, but a black area with a saw-toothed edge for sound track.

In the saw-toothed-edge type the light to the photo-cell is varied by blocking out varying portions of the sound track with the black area. If a large section of the sound track is examined at a time, a jagged edge is seen. But if we could peer at it when it passes by a 1-mil slit, we would see the area of clear film, through which light can pass to the cell, varying with the irregular variations of that edge. The effect is exactly the same as that of the other kind of

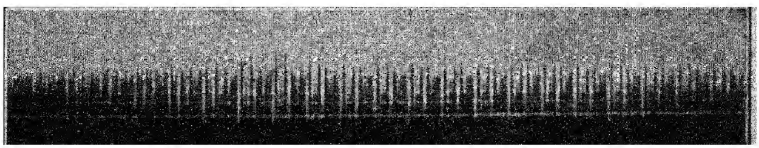

FIG. 17.—Constant-density, variable-amplitude RCA-Photophone sound track. Compare with Fig. 1 and with frontispiece.

sound track; both types of film can be played on any projector that will play either; they use different recording mechanisms, but that is another matter.

The jagged-edge sound track is said to be of the constant-density, variable-amplitude type. The kind of sound track we first discussed is called the variable density, constant amplitude. They are better known by the familiar names of the most prominent makers of each as R.C.A. and Western Electric, respectively. The 1-mil width of light beam is needed for the jagged-edge type as well as for the other, since the system must be responsive to teeth of that width if it is to reproduce the higher frequencies.

The thickness of the teeth in the R.C.A. sound track governs the frequency, exactly as the thickness of the lines governs it in the Western Electric track. The height of the teeth—the distance to which they stretch across the track and block out light—governs the volume, as density of line does on Western Electric recording. In the R.C.A. sound track, long teeth—great indentations of alternate black and white stretching nearly from one side to the other

of the track—represent high volume; short teeth, with the black and the clear areas almost equally divided, mean little modulation of light—low volume.

Ten Questions

1. Suppose through some accident to a slit assembly, or through a defective assembly, the height of the light beam, where it crosses the sound track, is increased to 3/1,000 inch. What would be the result in sound?
2. Holding a photo-cell up to a fairly bright light, and looking into the window, you notice the active lining is pinholed in a great many places. What effect would you expect in your sound?
3. The filament in an exciting lamp is not perfectly horizontal, but slopes downward. What effect would you expect in your sound?
4. Removing the sound gate and placing a card in front of the window of your photo-cell, you get a perfectly clear, white oval on one machine, but on the other, while the oval is equally well defined, its color is yellowish. What is the trouble? What is the cure? What effect would you expect in your sound?
5. Sound-on-film is noisy. Tap the exciting lamp and the monitor gives back the sound of your finger nail greatly magnified. What is the trouble and the cure?
6. Sound-on-film is noisy; rap gently with the butt of a screw driver on the optical assembly, and the monitor gives back the sound greatly magnified. Name three possible causes of this trouble and the cure for each.
7. Checking for the cause of no sound in movietone, you find you cannot hear anything when you connect your headphone in series with the photo-cell. Would this condition show you that the cell was not working?
8. You know your focus is not good, but there is no time to readjust it before running the next reel. What effect would you expect on the sound?
9. Where, in the photo-electric-cell circuit, would you look for the cause of noisy sound?
10. Where, in the exciting-lamp circuit would you look for the cause of noisy sound?

Ten Answers

1. Loss of volume on the higher frequencies, because the full modulating (varying) action of narrow lines will not be experienced; the band of light is too wide for these narrowest lines to have their full effect.
2. Loss of volume. Light from the exciting lamp striking the points where "active material" has dropped off will not elicit electrons from those points, consequently the total number of electrons flowing in the cell—the total amount of current flowing—will be less than should be the case for a given amount of light.
3. Bad focus, resulting in poor volume. Also possible noise; light of varying intensities upon the slit, so any slight variation of the slit relative to the exciting-lamp filament will result in varying intensities of light passing through the slit and reaching the photo-cell.

4. Oil in the optical train is causing the yellow light. Install a new optical train. Diminished volume in most cases, due to the fact that most photo-cells work best with blue and violet light.

5. The filament is loose in the exciting lamp. Change lamps. The lamp is loose in its socket, or the contact between the lamp and its socket is bad. Check spring contact, adjust it, or replace the socket, if necessary. Socket is loose in its clips. Bend clips for tight grip and firm contact.

6. A loose slit. A loose lens. In either case change the assembly. The light is not focused squarely on the slit. Adjust the focus.

7. Not always. With many cells the output is too small to work headphones, until after it is amplified. The only certain check on a photo-cell of this kind is to install one that has been tested on the other machine and found good.

8. Low volume. Loss of high frequencies. For reason given in answer 1.

9. A loose or rosin connection anywhere, but more especially a bad "grid leak," noisy B batteries, or a defective filter. Connect headphones directly across B batteries, or filter circuit, and listen for noisy output. The slightest sound heard from batteries indicates that batteries are bad.

10. Noisy batteries, or filter; loose or rosin connection, or a high resistance fuse. The same headphone test, as described in answer 9, may be applied.

CHAPTER II

MECHANICAL REQUIREMENTS OF SOUND-ON-FILM REPRODUCTION

If the system of "picking up" from a film record, which was treated in the previous chapter, is to work as it should, certain mechanical requirements must be met. Many experienced projectionists, even today, seem somewhat puzzled about these requirements. They are, of course, somewhat complicated, but not seriously so. Not even as complicated as an intermittent movement.

Especially do many projectionists feel that the mechanical requirements of sound-on-film are more troublesome than those surrounding sound-on-disc. This is largely an illusion. We have all of us been familiar with phonographs for years, and that fact breeds the impression, whether justified or not, of understanding them. No such impression helps us to have confidence in dealing with the other type of equipment.

As the previous chapter showed, the principles used in film pick-up are really simple. The mechanical requirements are even simpler. The mechanism by which they are met is somewhat more involved; details of it vary in systems of different makes; but in all systems it has to perform just the same functions. And no one of the most ordinary mechanical ability, who knows what those few elementary functions are, should have any trouble dealing with the apparatus for performing them which he finds in his own installation.

But let us go up into the projection room and examine this equipment. The film is our sound record, we know that. We also know that the film unwinds from the upper magazine and is reeled up again by the lower magazine; and that between these reels, while the film is "in the

machine," it serves two functions. Somewhere along the line it must pass squarely between the arc light and the distant screen, so that the light of the arc, interrupted and shaded by the images traced on the film, can form the moving picture. Somewhere else, before it reaches the lower magazine and is wound up again, the film must pass some device that extracts from it the secret of the sound with which it is entrusted. We easily find the place where this is done—the "sound aperture." Let us examine this aperture a bit more closely.

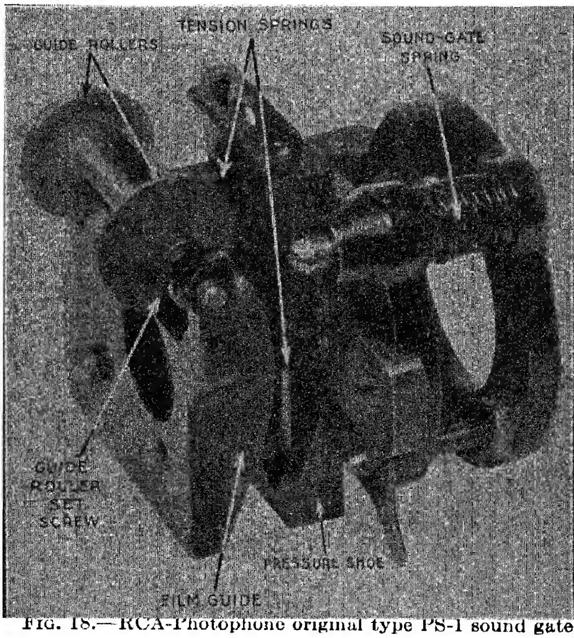

FIG. 18.—RCA-Photophone original type PS-1 sound gate.

FILM RIGIDLY HELD

The first thing we find, no matter what the make of our equipment, is that the film is held very rigidly when it passes the aperture. There is a sound gate of some kind that presses the film very tightly against its guides, allowing it to slide through easily, but not to flap the least bit. If it does flap, there will be flutter in the sound. There are

many causes of flutter in sound-on-film projection which will be considered later; this one may be noted in passing.

The Double Motion of Film

Let us thread up the film properly, and watch it as it runs through the mechanism. By directing our attention to the "light aperture"—the place opposite the lens where the arc light streams through to form the distant picture—we observe the film start and stop, start and stop. It moves with an intermittent motion; and we know, of course,

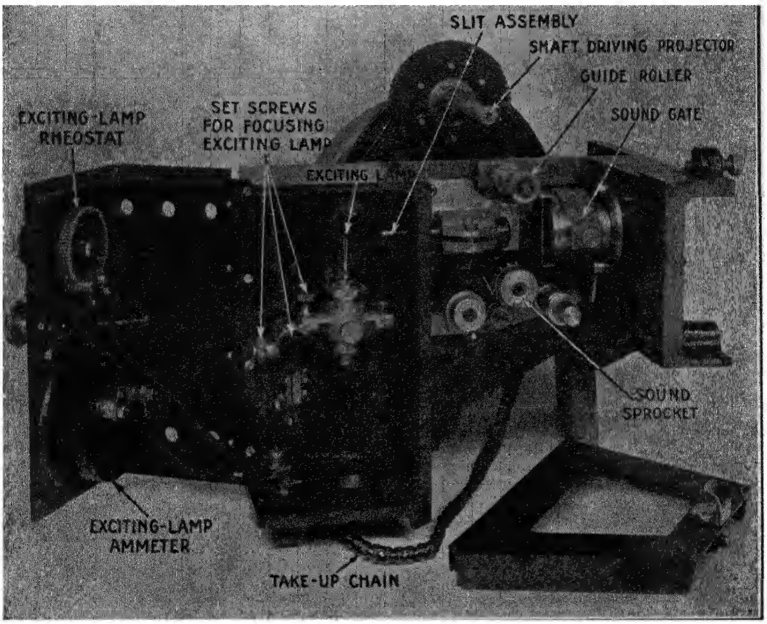

Fig. 19.—Western Electric D 86012 sound-on-film attachment.

that that part of the projector mechanism which causes this curious motion is called the "intermittent movement." We know, too, that such jerky progress, difficult to achieve, is an absolute necessity of light projection. The picture must be perfectly at rest while the arc light of this glorified magic lantern throws its image on the screen. A shutter is then dropped before the lens and that particular

picture is removed and another inserted. When the next picture is in place and motionless, the shutter is shifted out of the way. All this jerky movement must proceed at the rate of 90 feet of film per minute.

But when the sound gate is examined we find the film proceeding there with a flawlessly steady progress, not the least trace of jerkiness in its passage. Somewhere close

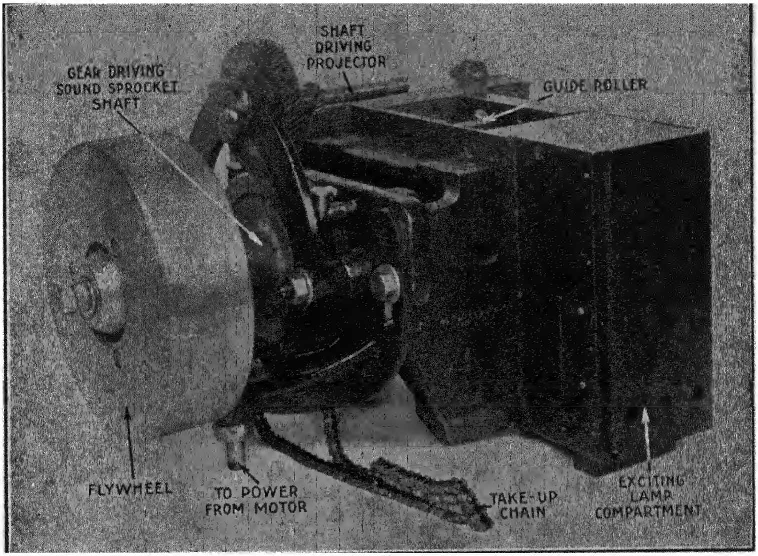

Fig. 20.—Western Electric D 86012 film attachment, rear view of driving side.

to the sound aperture, we find a second sprocket wheel, which moves steadily, without the slightest intermittent motion. Now, we know that there is only one motor driving this entire assembly, and from what we have already noticed we can deduce that there is a moderately complex system of gearing. Such a system in fact exists.

The Vital Loop

In the film, between the intermittent sprocket and the sound aperture, a loop small enough to be merely "slack," expands and contracts, with the regularity of a heart beat. This loop alone makes it possible for the film

to have an intermittent motion past the light aperture and a steady motion past the sound aperture, a foot and a half away as the celluloid winds.

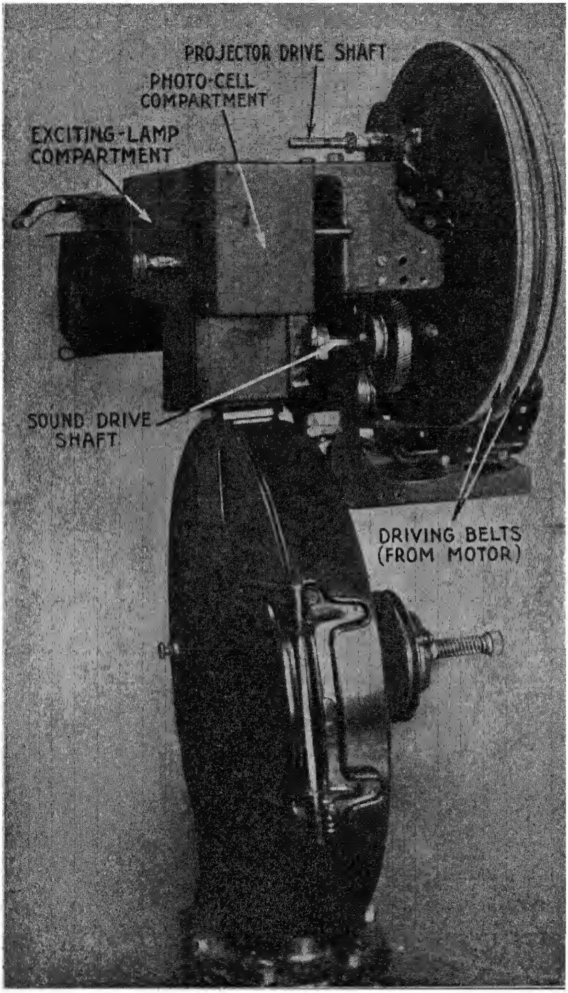

Fig. 21.—Western Electric type 206A (belt drive) reproducer set.

On examining the drive mechanism, we find that there are two driving sources, both geared to the main motor. One actuates the intermittent mechanism, just as that has

always been actuated, in the days before sound, just as if that shaft were geared or belted to a motor all its own. The second branch of motion drives the sound sprocket, causing it to rotate with a steady and flutterless action.

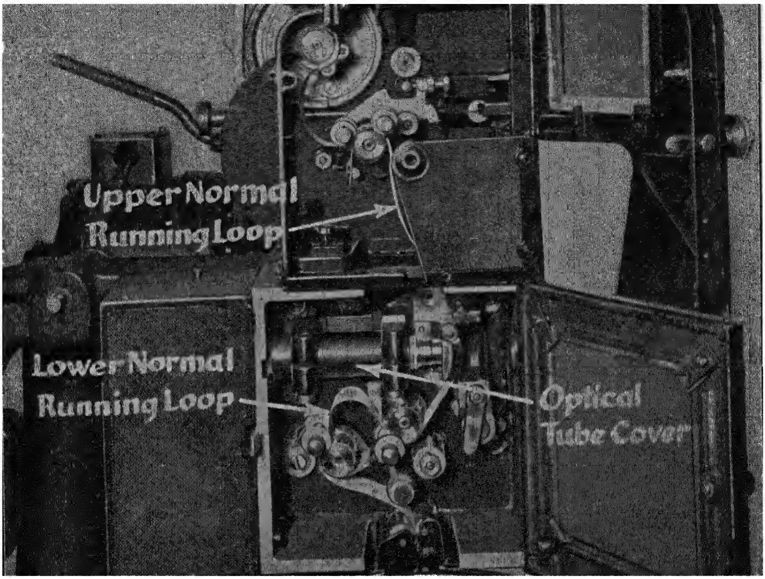

FIG. 22.—Pacent sound-on-film attachment, type for Simplex, showing film threaded up in projector and in attachment.

Mechanical Filters

The sound shaft in many cases carries a flywheel to smooth out traces of motor vibration. The film must pass the sound aperture with the same evenness of pace that the record needs when passing under the needle. Inside the Western Electric flywheel, for example—on some types of their equipment—may be found a mechanical filter composed of a circle of springs, very similar to the mechanical filter found underneath the Western Electric disc turntable. This system, in fact, uses two flywheels; one is used next to the motor itself to steady it, and the other, often with a mechanical filter inside, is mounted on the

shaft that actuates the sound sprocket. Rather similar filters are used by R.C.A., and other manufacturers.

The All-important Guides

Returning to the sound aperture, we find that the film is fed past it at a perfectly steady pace, rigidly held to prevent the smallest tendency to flap. We also find that the

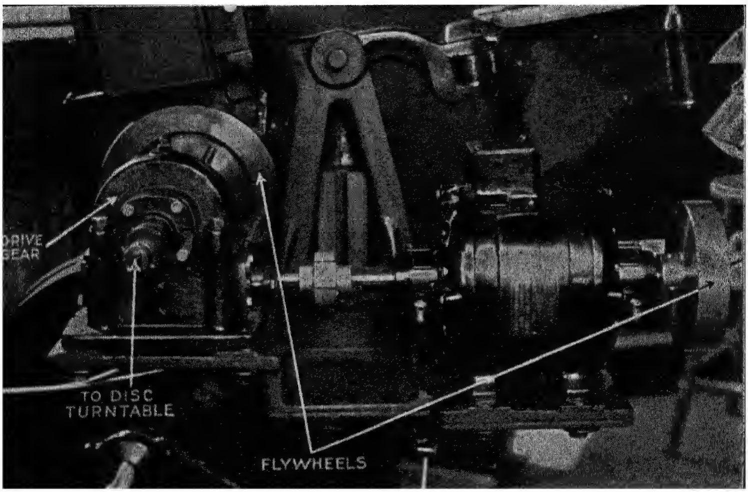

Fig. 23.—Royal Amplitone direct drive, type for Simplex only, disc and film.

film slides along past guides, guides so arranged and set that the sound track at the edge of the film, and nothing but the sound track, passes the sound aperture. If these guides are out of adjustment so that a portion of the picture, for example, passes the aperture, trouble follows. Every variation of light and shade in the picture that passes the sound aperture will, of course, act precisely like a variation of light and shade on the sound track.

The Guides Cause Trouble

Even those great inventive geniuses who created the photo-electric cell could not endow that cell with intelligence. It cannot distinguish between variations, in the

light reaching it, caused by a sound track and variations caused by Mary Pickford's blushes spreading to the wrong place. The projectionist may be too busy, or even too careless, to keep his guides lined up, or he may not have learned the necessity of doing so. Mr. Photo-electric Cell has only one job; he knows it thoroughly and it is very seldom that he falls down on it while he is fit to stand up and work at all. Any variation of light that reaches him is translated into sound currents; and whether that variation is caused by a proper sound track or by Miss Pickford walking into the edge of the picture is no part of his business. As a matter of fact, though, Mary does not fluster him much. Not even Greta Garbo and Clara Bow in one scene could affect him greatly. What he notices chiefly is dividing lines; those heavy black frames that separate each picture from the next. These cause the greatest variation in light when the picture moves over into the place where the sound track ought to be. The characteristic sound set up in that case, so loud that it masks most of the other effects, is known, indifferently, as "framing-line noise" or as "dividing-line noise."

Dividing-line and Sprocket-hole Noise

Dividing-line noise sounds somewhat like an airplane. But there is also a similar noise, "sprocket-hole noise." Sprocket-hole noise happens when the guides are out of line in the opposite direction, and some portion of the sprocket holes are passing the sound aperture. Because the nothingness in the center of the sprocket hole passes more light than the yellowish, imperfectly transparent film around it, there is a change in the amount of light reaching the photo-electric cell every time the edge of a sprocket hole, which is out of place because the guides are out of line, passes the sound aperture. To a given length of film there are more sprocket holes than dividing lines. Therefore, the light reaching the photo-electric cell will be altered in quantity more often by sprocket-hole noise than by

dividing-line noise. Since each alteration in the quantity of light creates one pulse in the electric vibrations within the photo-cell, which later become sound, it is obvious that sprocket-hole noise has a faster vibratory rate than dividing-line noise. Let this be repeated: More sprocket holes will pass the sound aperture in a second than dividing lines, because there are more of them to each foot of film. Therefore sprocket-hole noise has a faster vibration—a higher pitch—than dividing-line noise.

Both Sound Like Airplane or Motor-boat

Both sound like an airplane—the only difference is that sprocket-hole noise is pitched higher. Experience, or a little discreet experimenting after the show, will quickly teach anyone to distinguish between them. For the one, the guides have to be adjusted inward; for the other, outward.[1]

If either of these obnoxious noises occurs during the showing of the film, it can be remedied in almost any equipment without delay. The projectionist has only to listen to the sound in his monitor and adjust the guides until the disturbance disappears. But if he adjusts them too much he will bring in the brother disturbance, and be no better off. Also, the monitor, because machine noises are unavoidable in the projection room, is not the best possible help toward clearing up noise in sound. The projectionist cannot hear small disturbances clearly enough. If, after he has done his best, a member of the manager's staff, listening in the house below without distraction from noisy machines, reports some of the trouble still present, there is a second procedure that can be applied.

[1] A very fine airplane effect can be introduced into a scene that needs it, merely by holding the thumb against the outer edge of the film, just before it passes the sound aperture. Be careful that no portion of the hand throws a shadow on the aperture. The slight pressure will force the sprocket holes inward into line with the exciting light. Even the volume and pitch of the noise thus created can be varied somewhat by catching either the curved side or the full width of the sprocket holes.

Photographing the Sound Track

This is photographing the condition. A piece of blank leader is threaded up with the emulsion (dull) side toward the exciting lamp. The light from the exciting lamp is then photographed as a tiny black line, provided the leader is permitted to stand for from 5 to 10 seconds. The fly-wheel is then given a quarter turn, to move the blank film along, and another photograph is taken. In this way some five or six black marks are made by the light on the blank leader, which, of course, is threaded—as far as the sound aperture is concerned—exactly as any film would be. The blank leader is then removed and examined. The little black lines are about ⅛ inch long, and can be seen only if the celluloid is examined carefully. They are arranged along the film close to the sprocket holes. If they are so close to the sprocket holes that they overlap them, the guides are still out of adjustment. If they are too far from the sprocket holes the projectionist may be sure, even though no dividing lines show on the blank leader, that the guides are out of adjustment in the other direction. The little black lines should just barely clear, and *only* barely clear, the sprocket holes.

After adjusting the guides the blank leader may be reinserted and another series of photographs taken to check the new adjustment. Before this is done the old lines should be torn off or ringed with pencil, or marked in some other way to prevent subsequent confusion. Three or four sets of photographs are usually enough to clear up the most obstinate case of poorly adjusted guides; and this work can be done during the show, while the other projector is running.

Adjustment Must Be Permanent

Adjusting the guides is not enough; it is necessary to see that they stay adjusted. Different means are used in different systems to hold the guides, or guide—there may be only one—in position. In every case the means used

should be clear to the least experienced mechanic; but threads will wear, on such small parts, and the heads of set screws have been known to snap off under the screw driver. It will be well to keep surplus equipment on hand, against such emergencies. But the condition still experienced today—in the largest theatres, too—where sprocket-hole or dividing-line noise persists for hours until a service engineer can arrive to remedy the trouble, is without the slightest excuse, and is one which no self-respecting projectionist will tolerate in his projection room.

Is the Noise "in the Film"?

Sprocket-hole or dividing-line noise is occasionally "in the film"—placed there by defective recording or develop-

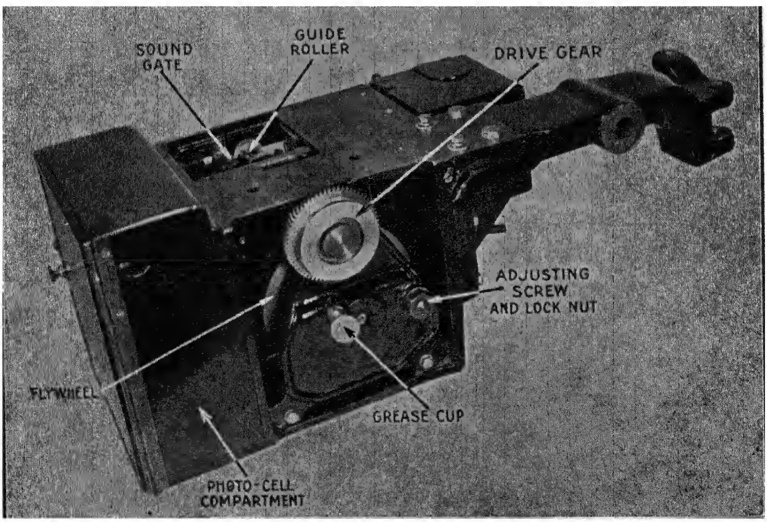

Fig. 24.—Drive side of RCA-Photophone type PS-1 sound head.

ing apparatus. Nothing can be done about this, of course, in the projection room. The condition is happily rare. The test of whether any noise is in the print or in the projection room is the same as for any such question, generally; if the same disturbance appears in the same place, time after time, and does not appear in other parts of the

picture, or in different reels, the print may fairly be blamed. However, there is an exception in the case of sprocket-hole and dividing-line noise; the film may not have been perfectly made. Either the picture or the sprocket holes may have been shifted very slightly from their proper places. If the shift is not too great, adjustments to the guides will clear up the trouble with the defective reel, without causing any in the case of perfect film. In other words, there is a slight latitude allowable in the position of the guides, which can be taken advantage of in such a case.

The film, then, slides down through the projector with a perfectly steady motion, imparted by the sound sprocket; passes before the sound aperture held tightly so it cannot flap; is guided carefully so it cannot shift; and is then wound on the lower magazine.

Flutter

Flutter is an extremely serious fault—not because it is hard to prevent or cure, but because it is often overlooked. Audiences and even managers, sometimes, do not know what the trouble is. They cannot define their sensations, but they know they are annoyed. This is very unfortunate for any theatre. If sound is noisy, or even breaks down altogether, patrons may say to themselves and their neighbors: "They had trouble at that house today, but I guess they'll fix it up all right by tomorrow." That criticism is serious enough, but not nearly as serious as when people, who do not know that there is any trouble, simply say, "Sound at that house is bad."

Flutter is not always easy to detect. Even a keen and thoroughly trained ear will sometimes miss it in dialogue. But it shows up readily in music. It puts a tremolo effect on all long-drawn notes—instead of singing "ahhhhhhh," the soprano seems to give voice to "ah-ah-ah-ah." The same is heard in the long-drawn notes of many instruments. Flutter is most easily detected in a piano number. It makes the piano sound harsh and "sour." *In general,*

whenever voice or music sounds harsh and "sour" look for flutter.

Flutter may, perhaps, be best defined as "unsteadiness in reproduction." It is what makes ordinary sounds resemble the bass notes of an organ; but long before it becomes strong enough for that resemblance to be clear it is strong enough to cause vague and unnameable displeasure to those who listen to it. Perhaps another way to describe it would be to say that it sounds the way unsteady projection looks. It is a fault against which theatre personnel must be on guard at all times, both to detect and to eliminate it.

Is Flutter in the Film?

Flutter is a defect very frequently found recorded in the film. Unlike sprocket-hole and dividing-line noise, a rather large proportion of flutter troubles in sound-on-film are traceable to defects in the recording or the developing apparatus, rather than to trouble in the theatre equipment.

As a check against this condition, it will be well to have at hand a special test reel, which is known to be clear of flutter. A piano recording is most commonly used for this. In the absence of such a reel the fact that flutter is found on everything run during the show—feature, short subjects, and all the shots of the sound news—is pretty clear indication that the projection-room equipment is at fault. Every scene of every reel that can show flutter at all—it is hard to catch in dialogue—is not apt to have flutter recorded in it.

Causes of Flutter

Assuming that flutter is known to exist in the projector, the question of locating the cause involves little more than common sense. There is no very practical way of analyzing flutter to determine just where it originates. Flutter may be caused by:

1. Anything that causes or allows the film to flap (move toward or away from the photo-electric cell) while passing the sound aperture. This may be a worn gate (tension

pad), worn guides behind the gate, or—what has the same effect—buckled film, for which there is no remedy.

2. Anything that allows or causes the film to move jerkily past the sound aperture. Undercut teeth on the sound sprocket will cause this, since the teeth in that case will not grip the film firmly, but will allow it to retain some of the intermittent motion imparted to it previously. The sound sprocket idler—pad roller—may be worn or may fit badly, failing to hold the film firmly against the sprocket teeth, which would cause the same effect. The sprocket holes may be torn or enlarged, especially in the case of an old print, for which, again, there is no remedy. Similar defects may be found in the lower sound sprocket, if there is one. If there is none, the take-up may be acting badly, because of lack or excess of grease, dirt, excessive wear, or a take-up chain which is too loose.

3. Or again, the sprockets themselves may be moving irregularly, through some defect in the gear that drives them. Worn teeth or a bent shaft may be the cause, or a shaft improperly fitted; for example, in systems where the head must be shimmed up to receive it, the shaft, instead of sliding in and out smoothly, may have been forced into place because of improper shimming. Excessive motor vibration may be transmitted past all gears and mechanical filters and may result in flutter. A flywheel may be improperly mounted, or defectively made, or the mechanical filter in the flywheel may be defective.

Take-ups Cause Flutter

In some systems there is a second sound sprocket between the sound aperture and the lower magazine; in others there is none. When there is none, the take-up, which rotates the lower magazine reel and causes it to "take up" the film, can give rise to flutter. Because the take up is a friction clutch, it can give trouble in many ways either from wear, from too much or too little oil being used, or from some fault of the chain or belt that moves it. Both stretch with use, and when stretched too far, they no longer exert a steady

pull against the take-up; then flutter results. In spite of the fact that there is a steadily moving sprocket also

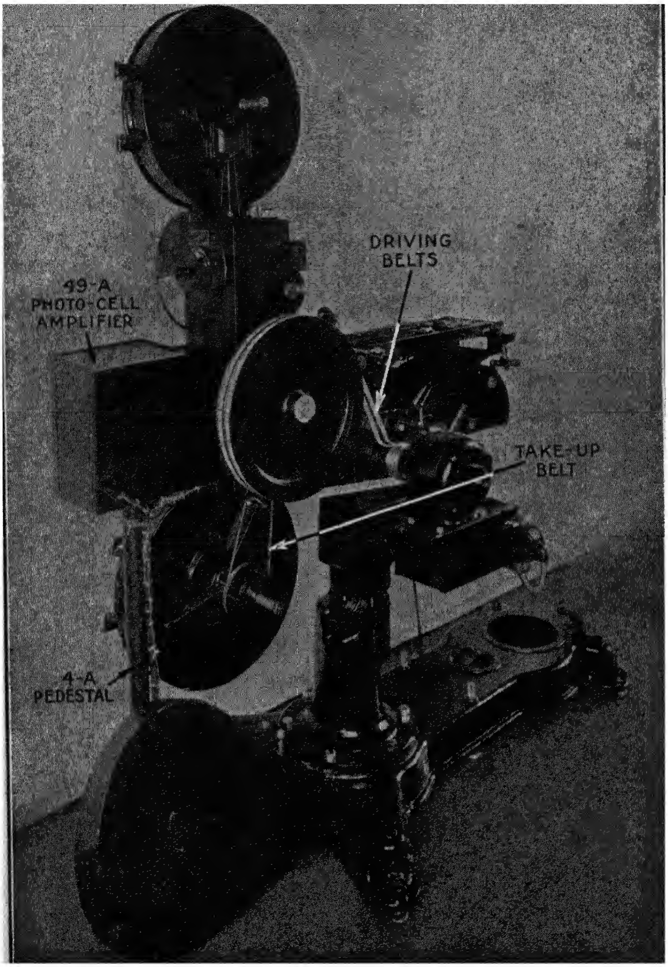

FIG. 25.—Driving side of Western Electric type 206A reproducer set.

pulling the film down, flutter may follow when the take-up acts irregularly. Most cases of flutter in sound-on-film, where there is no second sprocket between the sound aper-

ture and the lower magazine, are traceable to the take-up or the take-up chain. This chain must have some play, but not too much; if it has become exceptionally loose, it should be tightened, links being removed if necessary. Similar considerations apply to a belt. When this treatment does not cure the condition, the take-up itself should be inspected, disassembled and examined for signs of wear that would prevent it from working properly. Surplus grease and dirt should be cleaned away, and the take-up re-oiled.

Since any condition that allows the film to be pulled past the sound aperture with the least trace of intermittent motion will cause flutter, there are many things to consider when a question of flutter arises. Therefore it will be well to make sure, before anything else is done, that flutter does exist and that it is due to the projector, and not recorded in the print.

Flutter Is No Mystery

None of the causes of flutter is, or should be, beyond repair by the competent projectionist. Many, of course, call for replacing some part or parts of the equipment. Worn gears or undercut sprockets are not matters for repair in the projection room, but of replacement.

The amount of space that would be required naturally forbids a detailed description here of all the types of gear,[1] belt, and chain drives now on the market There are a number of manufacturers, and some of them have several models of this portion of equipment. The exact detail of each nut, bolt, and set screw of some two dozen drives does not fall within the scope of this book.

[1] Do not take any gears apart to analyze them before trouble makes this necessary. In the great majority of cases flutter will be found to be due to one of the other more easily accessible causes given. In some makes of equipment, gear trains of this kind are so carefully lined up at the factory as to make it problematical whether they will ever run as smoothly as they once did after they have been taken down and reassembled without special apparatus for doing the job.

Review

For the sake of clarity, then, before we pass on to newer and possibly more interesting matters, let us review what has been stated here.

As the very foundation of picture projection, it is necessary that the film should pass the light aperture with an intermittent motion. It is equally necessary, as the very foundation of sound projection, that the film shall pass the sound aperture with an absolutely steady motion. This is as important as that the disc record shall move under the needle with an absolutely steady motion; in either case any jerkiness results in flutter. A loop, or slack, is provided between the intermittent sprocket and the sound sprocket to allow the same film to undergo these two different forms of motion; and a loop that is too tight is one (temporary, of course) cause of flutter.

Sprocket-hole and Dividing-line Noise

The sound track must not only pass the sound aperture with a steady motion—it must pass the sound aperture by itself. If portions of the picture pass the sound aperture along with the track, that is, if the film is out of place because of poorly adjusted guides, or of guides that slip their adjustment, dividing-line noise will result. The guides must then be adjusted to move the film inward, until the dividing lines are back where they belong. If the guides are out of place in the other direction, so that sprocket holes pass the sound aperture, sprocket-hole noise will result. Both noises sound like an airplane, but the sprocket-hole noise is higher in pitch, because there are more sprocket-holes than there are dividing lines. For this reason the light will be changed in intensity—modulated—more often per second by sprocket holes; the resultant electrical vibration created by the photo-electric cell will be of higher frequency—the sprocket-hole sound will have a higher pitch, or tone. Experience will soon teach any ear to distinguish between the two sounds.

Their Cure

Sprocket-hole and dividing-line noise can be quickly found and eliminated, while film is running, by listening to

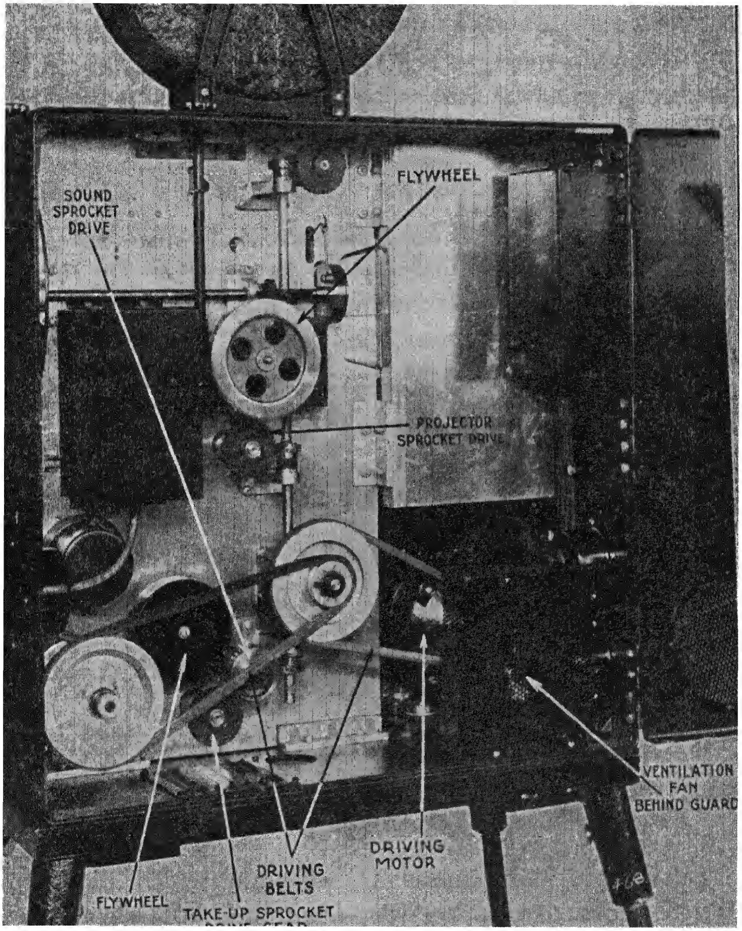

FIG. 26.—Drive side of RCA-Photophone model 4PP-6B portable projector.

the monitor and adjusting the guides. If the projection room is too noisy to allow proper judgment by this means, the adjustment can be photographed on blank leader while the other machine is running, allowing the leader to rest

from 5 to 10 seconds for each exposure, and the guides can be adjusted on the basis of three or four such series of photographs, one set being taken after each new adjustment. A quicker method, which can only be used when there is no audience in the house, would be for some member of the manager's staff, or a projectionist, to stand near the screen, listening to the sound, and motioning to the projection room to shift the idlers to right or to left, until the trouble is eliminated.

Flutter Causes in Two Classes

Flutter, we found, is due to a myriad of causes, no one of which can be named merely by listening to the sound, although a projectionist familiar with his equipment would know which part was most likely to give trouble. Flutter

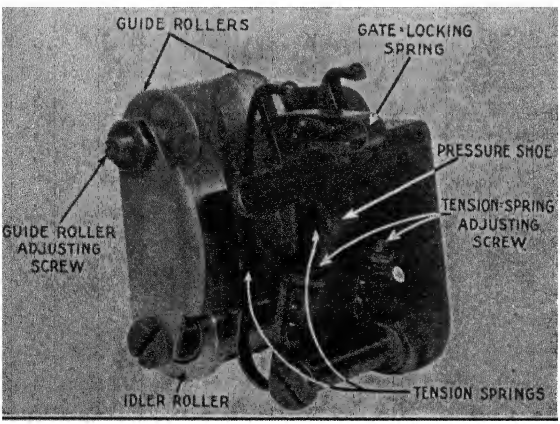

Fig. 27.—RCA-Photophone sound gate for types PS-14 and 16 sound heads.

is due to two main causes: (1) anything which allows the film to move toward or away from the photo-electric cell while passing the aperture. This trouble is readily cleared; that portion of the mechanism which holds the film as it passes the sound aperture is fitted poorly or is worn. Or the film itself is buckled; nothing can be done about that. (2) Anything that causes or allows the film to move past the sound aperture irregularly, or with any trace of inter-

mittent motion. Starting at the beginning, this may be excessive motor vibration, defective mechanical filters, including flywheels, which allow normal motor vibration to come through, or defective or misaligned gears or shafts which introduce new vibration after the transmitted power has passed the mechanical filters but before it reaches the sound sprocket. Any or all of these things will allow the sound sprocket to move irregularly, and so transmit irregular motion to the film passing the sound aperture.

But even though the sound sprocket rotates with perfect smoothness, it may not be imparting equally smooth motion to the film, for a number of causes. Its teeth may be undercut, or the idler that is intended to hold the film firmly against it may be worn or badly adjusted. If there is a second sprocket below, it, or its idler, or its driving gear may be similarly defective. If there is no second sprocket below the sound aperture, the take-up, or its chain, may be causing a jerky pull on the film.

Ten Questions

1. What, between the intermittent sprocket and the sound sprocket, absorbs the intermittent motion of the film?
2. Flexible connectors are often used between the motor and the disc turntable to absorb motor vibration. Why are they not used between the motor and the projector for sound on film reproduction?
3. What means are used to smooth out motor vibration for sound on film?
4. Describe the sound of sprocket-hole and dividing-line noise.
5. How can they be cured by running the machine?
6. How can they be cured without running the machine?
7. Describe the sound of flutter.
8. How do you tell if flutter is in the print or in your projector?
9. Name one class of causes of flutter and four causes in that class.
10. Name another class of causes of flutter and 20 causes in that class.

Answers

1. A small loop.
2. The power to be transmitted, due to the greater work involved in moving the heavy projector mechanism, is too great for such weak devices.
3. Flywheels, and sometimes mechanical filters. The extensive gear system and the inertia of the heavy mechanism also help toward this end.
4. Both sound like an airplane. Sprocket-hole noise is higher in pitch than dividing-line noise.

5. By having someone listen to the sound of them, at the monitor, or preferably in the theatre, while a second person adjusts the guides in and out until neither noise is heard.

6. By photographing the sound track; exposing successive sections of blank leader, properly threaded up, to the exciting light for a few seconds at a time. Faint black lines will be photographed upon the leader. The guides should be adjusted and the photographing repeated until the edges of the black lines *just* clear the sprocket holes. This adjustment can easily be completed in the time the other machine takes to run one reel.

7. "Sour" sound. All long-drawn notes have tremolo effect. They sound like the low tones of an organ—"shivery." Piano playing has an unpleasant, rattling effect. In less severe cases, music, and sometimes voices, merely seem mysteriously unpleasant.

8. (A) By running a special flutter test reel, or any reel on which flutter can readily be detected, that is any reel which has piano, or musical selections involving drawn-out notes—and is known to be clear of flutter. (B) By playing the suspected reel on the other projector—although both projectors can easily be afflicted with this trouble at the same time.

9. Anything that causes or allows the film to flap—to move toward or away from the exciting light—while it is passing the sound aperture, such as (1) loose tension pad, (2) worn guides on pad, (3) worn guides opposite pad, and (4) buckled film.

10. Any causes that allow the film to move past the aperture with an unsteady motion. Such causes are (1) worn take-up, (2) overgreased take-up, (3) ungreased take-up, (4) take-up chain too loose, (5) take-up chain too tight, (6) undercut sprocket teeth, (7) enlarged sprocket holes in the film. Further causes are: sprocket moving unsteadily, due to: (8) worn sprocket roller, (9) worn sprocket shaft, (10) defective gear actuating sprocket, (11) defective flywheel, (12) defective mechanical filter, (13) any loose connection between sprocket and motor, causing power to be delivered to sprocket irregularly, such as loose set-screws or couplings; (14) head defectively shimmed up (on some equipment), (15) defective mesh of gears due to any other cause, (16) wear or defect or lack of lubrication in motor bearings, causing excessive motor vibration, (17) bad brushes or commutator or any other electrical cause of excessive motor vibration, (18) any defect in motor speed control causing or allowing motor to move irregularly; (19) too short a loop between intermittent and sound sprockets; (20) excessive vibration of projector head, transmitted to sound sprocket. Flutter is cured by process of elimination, helped by probabilities based on previous experience of the same projector.

CHAPTER III

SOUND-ON-DISC

If the sound groove of any record is examined, here and there will be found places where the groove visibly deviates from side to side. This swing is more obvious in some places than in others, but a lens will reveal that every portion of the groove—except the silent portions—swings in just the same way.

While threading the groove, the needle is pushed from side to side as it follows these irregularities. But, from the standpoint of the needle, the record moves rather fast. The corresponding motion of the needle is, consequently equally fast—fast enough to be called a vibration, rather than a motion.

Where the sound recorded was high in pitch, the swings follow each other more rapidly, therefore they are abrupt. The needle, of course, moves from side to side, or vibrates, with equal rapidity. Where the sound recorded is low in frequency, the swings follow each other more gradually, they are gentler, and the vibrations of the needle are correspondingly slower.

Where the sound recorded was loud the swings are broader, that is, they cover a greater distance from side to side, than when the sound was low. The needle must likewise swing over a greater distance, therefore, its vibration is stronger, because it has to cover more space in the given time.

The vibration of the needle thus corresponds exactly to the air vibrations of the original sound. Since the needle sets the air about itself to vibrating, on a small scale, exactly as the diaphragm of a loud speaker does on a larger scale, its motion can be heard. A record can be heard when all the amplifiers are detached, simply by putting the

ear somewhat close to the needle. Often the sound from the record can be heard 10 feet away from the needle, depending on the mechanical construction of the reproducer. As you listen to it, it sounds "tinny," just as a Steinway piano would sound tinny if the mechanism were played apart from its casing, and for the same reason—lack of any sounding-board to create a more mellow effect.

The old-fashioned phonograph had no electrical pick-up. The needle was fastened to a small, flexible disc, usually of metal but sometimes of mica, and this disc vibrated with the needle vibrations. Its effect upon the surrounding air was naturally greater than the effect of the slim needle could be. The air vibrations so set up were concentrated, and somewhat modified and mellowed, by a wooden horn. But there was no increase of power, no way to multiply the output until enough sound could be created to fill a theatre. The air vibrations, known as sound, cannot be amplified—a horn merely concentrates them. Electric currents can be amplified by means of vacuum tubes. Therefore the theatre uses an electrical pick-up which translates the needle vibration into electrical vibrations; and leaves to the "units" of the loud speakers the work of converting these currents (immensely strengthened) into air vibrations—or sound.

The Reproducer

If a reproducer were taken apart—do not try it—inside would be found a magnet quite similar to the horseshoe magnet which we all played with when we were younger. Also, glued to the back of a little disc that vibrates with the needle there might be a small coil of fine wire.[1] This coil of wire is the "armature," and because it is glued firmly to the little metal disc, it vibrates with the vibration of that disc. Two wires lead from it, and as we follow these later we shall find that they ultimately arrive at the amplifiers.

Inside some, but not all, reproducers, oil is also found. The function of the oil is to "damp" the action of the

[1] Reproducers vary in construction. Another type is described later.

armature. Since the armature is intended to vibrate, it may seem odd that oil should be introduced to damp (choke) out this vibration. But anything that is capable of vibrating at all has a natural vibratory frequency; that is, there is some particular rate of vibration, depending on size, shape, weight, and other factors, at which it will vibrate most easily. Even the little armature of the reproducer is afflicted with this universal complaint of vibrating objects. Therefore oil is introduced for the armature to push against so that it will not reproduce a few selected notes much more strongly than the rest. In most types of reproducers, however, no such "damping" means is required; the armature being so designed that its natural vibration point is far from those frequencies of vibration that come within a range the human ear can appreciate as sound. In others, the distortion is calmly permitted, and compensated for by an electric "equalizer," placed elsewhere in the circuit.

FIG. 28.—Magnified cross-section of grooves in a disc record.

But today, one is more likely to find the reproducer designed on a slightly different, and on a very slightly more complicated, principle. There is no metal disc. The armature is designed like a metal rod which seems to form an extension to the needle, and which is so mounted as to be free to vibrate. There is a horseshoe magnet, and between the ends of this, a coil of fine wire is wound around a hollow core. The armature extends upward into the hollow of this coil, but the coil does not move. There are several variations of this form of construction but the principle of the action is much the same in all types.

AN IMAGINARY EXPERIMENT

Now suppose we have bought a little horseshoe magnet in a ten-cent store and suppose also that some kind friend

with an electrical laboratory at his disposal has lent us a very sensitive galvanometer. We shall short-circuit the binding posts of the galvanometer—it is only a more sensitive ammeter—with a loop of wire. We notice that whenever we move the magnet in the vicinity of the wire the instrument registers a current.

Pick-ups Are Power Houses

There are no batteries in the circuit, nor is there any other source of power. We are generating electricity in that scrap of wire. Let us go a bit further. We notice that when the magnet is at rest no current is set up, no matter how close the magnet may be to the wire. If we have a bit of slack in the wire and try moving that, we find that it makes no difference whether we move the magnet or the wire—motion in a magnetic field sets up a current.[1]

Strength of Induced Currents

In the reproducer we found a coil of wire set close to a magnet, and the coil vibrating. We can now understand that a current is set up in this coil.[2]

Now suppose we take a longer piece of wire—the soft-drawn copper No. 18, sold as "bell-wire," is excellent for the purpose—and wind it about a round lead pencil, keeping the turns as close together as possible. If we slip the pencil out of the coil we have made, it will keep its shape, and we

[1] The direction of the motion is important. The magnetic "lines of force" must cross (or "cut") the conductor, for if they run parallel to it, no effect will follow.

[2] Incidentally, the experiment need not be imaginary. In your projection room you may have a low-scale milliammeter such as is furnished with some installations for measuring the plate current to the smaller tubes. You might disconnect that, taking care to get the polarities right when you put it back. Any instrument with a scale of less than 20 milliamperes will show results, and the finer the scale the more accurate the results will be. Or your radio dealer will have such a meter, which he uses for testing radio tubes. A powerful horseshoe magnet out of a magneto can be bought for a few cents at any automobile repair shop—the mechanic will likely give it to you, and thank you for carrying it away. With these instruments and a bit of wire you can reproduce the experiment if you wish to.

can connect the two ends of it to the binding posts of the galvanometer as before. We at once see that motion of the magnet near this coil gives a much stronger result than the same motion near a single wire. We see now that there are a number of turns of wire glued to the back of the armature, instead of one turn, in order to create a stronger current.

Mechanical Vibration Converted into Vibrating Currents

The needle swings from one side to the other in the groove, following the waverings as the walls dictate. With

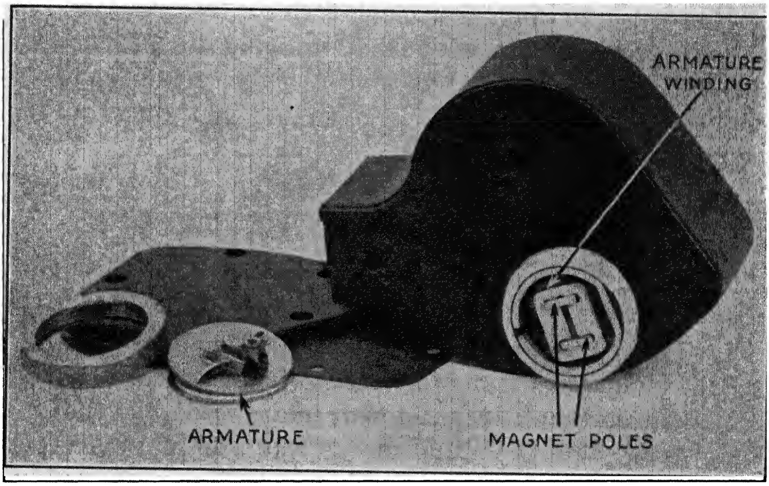

Fig. 29.—The Western Electric type 4A disc reproducer, side view, covers removed.

each swing the armature approaches the magnet, and then draws away again. For each swing a pulse of current is set up in the coil. One surge of current is made for each swing of the groove. The frequency with which the needle swings back and forth represents the frequency with which the groove wavers from side to side, and the frequency of these waverings represents the frequency of air vibration of the original sound. It follows then that a wavering current

is set up in the coil whose frequency reproduces, minutely, the pitch, or tone, of the sound recorded.

Suppose in the recorded sound two notes follow one another, the first soft, the second loud. The difference in pitch between these notes, we have seen, will be represented on the record by a difference in the spacing of the waverings; that is, when the record is rotating at constant speed, by a difference in the frequency, or rapidity, with which the waverings follow each other. The difference in strength, or intensity, will be represented by the *extent* of the waverings—by how *far* they swing from side to side: the needle, following the wider swings, will move more strongly for louder sound.

Returning to our experimental apparatus, we can convince ourselves in a moment that swinging the magnet past the coil more strongly will give a higher reading on the meter—a stronger current is generated in the coil of the reproducer.

And this is the whole of the simple secret by which the "sound-box" reproduces sound from disc records.

The Moving Nail

But we saw that many reproducers had both the armature coil and the magnet locked down and fastened, and that the only thing about them that moved was a bit of metal stuck into the hollow center of the coil. A slight variation of our experiment will show how this type functions. We made a coil by winding wire around a pencil, and then pulling the pencil free. Let us take a match and move it about in the hollow of our coil, coil and magnet being close to each other, as before. But that's a disappointment; the meter shows no results, unless, of course, the coil is accidentally jogged in moving the match.

If however we use a wire nail, a meter indication follows. Moving a wire nail about inside the hollow of our coil creates current just as if the coil itself or the magnet were

moved. In short, *the strength of the magnetic field, as it passes through the coil, is being altered.* Evidently the soft iron nail conducts the force of the magnetic field better, or worse, then air does. (As a matter of fact, soft iron is a much better conductor for magnetic power than air is.) In those reproducers, then, which use only a bit of moving metal to move with the needle, the effect upon the electrical relations of the magnet and the coil is precisely the same as if either of *them* were moved.

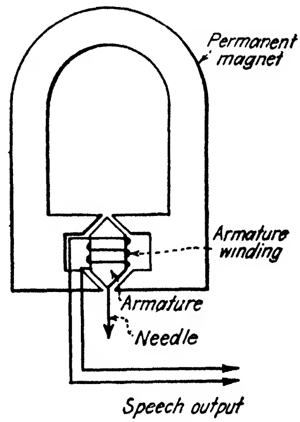

FIG. 30.—Diagram of typical disc reproducer.

A General Law Worth Remembering

In short, we may here, as a result of our experiment, formulate a general electrical law: *whenever the strength of a magnetic field is altered, a current of electricity will be generated in any electrical conductor within that field.* It does not matter if the alteration of the strength of the field results from moving the magnet, or from moving the conductor, or from moving within the field a better or a worse conductor of magnetic force than air or—as we shall see later in the case of electro-magnets—from changing the power of the magnet.

For the benefit of any who may still be hazy about this simple reproducer action, let us review it very briefly.

Any change in the strength of a magnetic field sets up a current in any conductor lying within that field.

Such a change in strength can be produced by motion of the magnet; motion of the conductor; or motion of some third body, lying within the field, which is a better conductor for magnetic force than air is.

One pulse of current will be created for each movement. If the movement is vibrating, a pulse of current will be created for each new motion. Consequently the pulsat-

ing current will follow, in frequency, the frequency of the mechanical vibration that caused it.

The strength of the current will be proportional to the strength of the motion.

In disc reproduction, the strength of the motion of the needle is governed by the distance through which the sound groove swings from side to side. This swing can easily be seen under a lens. It is so recorded that its extent is in proportion to the loudness of the original sound.[1]

And the frequency of the original sound is recorded in the spacing of these swings. When the record is played at the proper speed, the needle will swing, that is, vibrate, at the original frequency, and therefore a current corresponding to that frequency will be set up in the reproducer coil.

Do Not Open Reproducers

No attempt should be made to repair a defective reproducer in the projection room. Many portions of the sound equipment can be repaired there, but the reproducer is not one of them. It is a sensitive and extremely delicate piece of apparatus. Any improper repair is extremely likely to bend the armature slightly, or add a minute bit of weight or drag to it or subtract minutely from the weight or drag. The slightest change of this sort will change the "fundamental" of the armature—the frequency at which it vibrates most comfortably. It will then tend to reproduce some notes more strongly than others, because it will vibrate more strongly at notes near its new fundamental, and so set up highly unpleasant distortion in your sound. The factory is the place to repair defective reproducers, and after they are treated there by expert workmen who do nothing else, they need a very careful laboratory test to make sure they are fit for further use.

[1] See chapter on Recording.

Speech Currents Fed into the Main System

If the system is equipped for film reproduction also, the current is led from the reproducer to a film-disc, changeover switch, that is, a switch that enables the projectionist to connect either the disc or the film pick-up output to the amplifiers. From this switch the wires lead into the fader. The fader often has more than one function, and among its functions may be that of a switch, serving to connect either of the two projectors to the amplifier.

Details to Follow

The changeover film-disc switches are of several types. Sometimes they are plain switches; sometimes, keys with numerous contact prongs; sometimes, keys of this sort operated by relays.

In most systems, the fader, whether or not it serves as a switch to connect either of the two projectors to the amplifier, will have the duty of regulating volume.[1] It most commonly consists of two resistances, arranged end to end in a semicircle. Each resistance is in series with the output from one projector. As the contact arm is moved, greater or less opposition to the passage of the current is introduced, and the current that reaches the amplifier will be stronger or weaker accordingly. To change to the other projector it is merely necessary to swing the contact arm over to the other resistance.

Exact circuits will be discussed in a future chapter.

Ten Questions

1. A reproducer was dropped while it was installed; the disc sound from that machine has been "fuzzy" since. What is the trouble with the reproducer? Can it be repaired in the projection room?

2. The best steel does not hold its magnetism forever; magnets grow weak with time. What difference in sound could be expected from a repro-

[1] *Important:* This is *not* true of RCA-Photophone equipment. That company, unlike most others, uses the term "fader" to designate a device used only for changing over between projectors. A volume control associated with the system amplifier is the only means employed by R.C.A. to govern the intensity of sound.

ducer that is old, but otherwise in perfect condition, as compared with a new reproducer?

3. There is no sound from one machine. How would you check with headphones to determine if the reproducer is working, and what could you do about it if it were not?

4. What effect has change in the strength of a magnetic field on a conductor cut by the lines of force of that field?

5. If the change is a continuous vibration what will be the effect?

6. The frequency of the change will have what effect?

7. The extent of the change will have what effect?

8. What is meant by "natural rate of vibration"?

9. What trouble may it cause in disc reproducers?

10. What two methods are used to avoid this trouble? What method is used to counteract its effects?

Ten Answers

1. The armature is bent, or loose, or the magnet is loose. Repair and test after repair are factory jobs.

2. Weaker.

3. At the wires leading from the reproducer. Disconnect them from the leads going to the amplifier, and connect to your headphones. Change reproducer; attempt repairs only if you have no spare and can not get one for a long time.

4. Generates, or induces, a current in that conductor.

5. The current induced will be vibratory.

6. The induced vibrating current will follow in frequency the frequency of the vibration that creates it.

7. It will be reproduced in the strength of the induced current.

8. The tendency of any vibrating body to vibrate most strongly at some given frequency which will depend upon its construction.

9. The tendency to reproduce some frequencies more strongly than others, as when the armature vibrates more strongly than called for at frequencies nearest its natural rate.

10. Oil damping. Or design tending to keep the armature's natural rate away from the range of sound frequencies. Subsequent compensation with an electrical "equalizer."

CHAPTER IV

MECHANICAL REQUIREMENTS OF SOUND-ON-DISC

The synchronous disc must carry enough sound to last during a full reel or 20 minutes. The ordinary phonograph record plays for 5 minutes or less. If the synchronous disc used the same sort of sound groove as the ordinary record, it would have to be 40 inches in diameter.

Since this is impracticable, the synchronous sound record must be crowded. It is crowded by playing the record more slowly as well as by putting the grooves closer together. As a result of both kinds of crowding, precautions are needed for synchronous disc reproduction that are not required for non-synchronous or for ordinary phonographs.

Most of the mechanical considerations involved in synchronous sound-on-disc are moderately obvious upon reflection, and fairly well known to experience. However, some adjustments, for example, the proper placing of the reproducer arm pivot, seem not to be generally understood; others, perhaps more familiar, could stand a word of review. In the interests of completeness, we shall glance over the whole here, and if anyone finds himself bored he can always pass on to the next chapter.

The Turntable

First, as we examine the mechanism, we see a turntable, a rotating plate on which the record rests. This is generally surfaced with felt. The felt is there to provide friction. If the top of the turntable were perfectly smooth, the record might slip on the turntable. If the record were to slip, the sound would flutter. For the same reason a weight or clamp is often placed over the center of the

record and serves as an additional precaution against flutter.

If a level were placed on top of your turntable, you would find, assuming the equipment to be in good condition, that the turntable is level in every direction. If it is not, your equipment needs immediate attention. If the turntable is not level, the needle, moving toward the outer edge of the record, may be either climbing uphill, or sliding downhill. Now the groove in which the needle slides is not as deep as on non-synchronous records, neither are the sides of it as strong. If the turntable slopes toward either side, the pull of gravity on the reproducer will obviously tend to make the needle jump out of the groove and go downhill, or possibly to break down a wall.

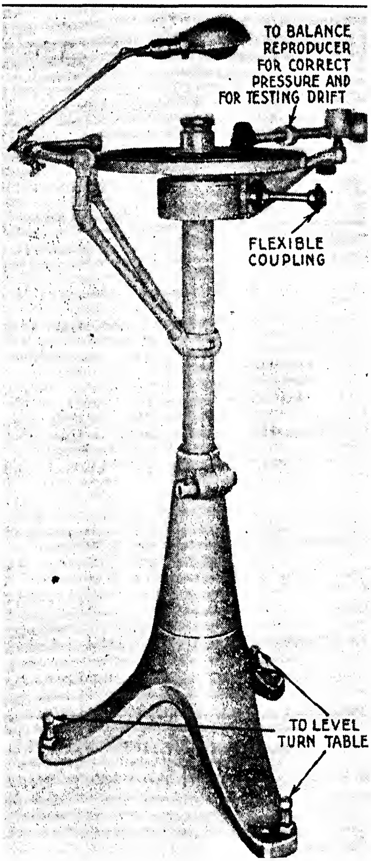

FIG. 31.—Pacent standard-type synchronous-disc turntable, showing flexible coupling and adjustable bolts for leveling.

If it does no other damage, a turntable which is not level will cause the needle to rub more strongly against one side or the other of the groove, and the friction thus set up will cause additional "needle noise." There is enough of this present under the best conditions, due to the pressure of the point of the needle against the bottom of the groove, and normal friction against the sides.

Grooves May Go Mountaineering

But the turntable can be off level in still another way. The needle, as it traverses the record, may move across a perfectly horizontal path, that is, the turntable may be level from side to side, but it may still be tilted forward or backward. In that case the grooves, as they pass under the point of the needle, will be moving uphill, or downhill. This condition is almost as bad as the other. The angle at which the needle meets the record is changed.

1. If the grooves are traveling uphill, the point of the needle cuts too deeply into the bottom. Excessive friction creating increased "surface" or "needle" noise will be one result; in addition, this friction may cause a miniature collision between the point of the needle and an exceptionally tough spot in the record, compelling the needle to jump.

2. If the grooves are traveling downhill, a broader portion of the needle than usual will be introduced between the walls. This may result in excessive side friction and, consequently, in increased surface noise. It may also result in loss of high frequencies, because the broad upper part of the needle will not be able to follow the very short waverings with which the higher notes are recorded. Lastly, the groove may at some points be so narrow that the broader portion of the needle will not fit in at all, but will either jump or break down the walls.

Nearly every make of turntable is equipped with some means of leveling, to compensate for imperfect floors. Only a few of these means are so well developed that a turntable, when once installed and found to be level, can be left alone. For all other installations frequent check (about once a week) with a "spirit" level and prompt correction of any irregular condition that may have appeared are among the elementary necessities of good disc reproduction.

Turntable-to-motor Couplings

So far we have examined the turntable at rest. Let us put it into rotation. We find it is driven by a motor, to

which it is coupled, in most cases, by some sort of shaft and gearing. Nearly all manufacturers use rubber for the connecting shaft, or for some parts of it.

The reason for such an unusual procedure as using a rubber connecting shaft is, of course, that rubber is flexible. It takes up much of the vibration of the motor. If the coupling were rigid, this vibration might be reproduced in the sound as flutter. Each tiny jump or delay of the vibration would cause a corresponding jump or delay in the progress of the record under the needle. An audience might describe the resultant sound as "fuzzy."

Rubber tends to harden with age; therefore a rubber coupling shaft may need to be changed after it has been in use for a while, depending on its condition. Oil will rot rubber and a connecting shaft that has been accidently spattered with oil, and has absorbed the oil, had best be changed. Otherwise, it is likely to break in the middle of a reel, or at some such awkward time. An oil-soaked connecting shaft should not be trusted.

Vibration Filters

Precautions against flutter which is due to motor vibration sometimes go beyond a flexible connection. In many systems there is an elaborate "mechanical filter," designed to smooth out any flutter that may pass the rubber connectors. The Western Electric type of filter works in this way: the power from the motor is transmitted to one end of a set of coiled springs, arranged in a circle; the other end of this set of springs is fastened to the turntable. Thus the motor, as it turns around, moves the flexible coupling shaft around; this shaft, through a gear connection, moves the springs around, and the springs pull the turntable around. Under the springs of the filter are a set of vanes, rotating with the turntable, which move in a bath of heavy oil. These tend still further to damp vibration, and to produce an absolutely steady motion.

The springs of this filter very seldom give any trouble, but the oil bath may, during extremely cold weather.

The oil tends to thicken, increasing the pressure against the vanes. This puts an increased strain on the whole system, and the weakest link snaps. The weakest link happens to be the rubber couplings, which tear or twist loose. When that happens the show stops. It usually

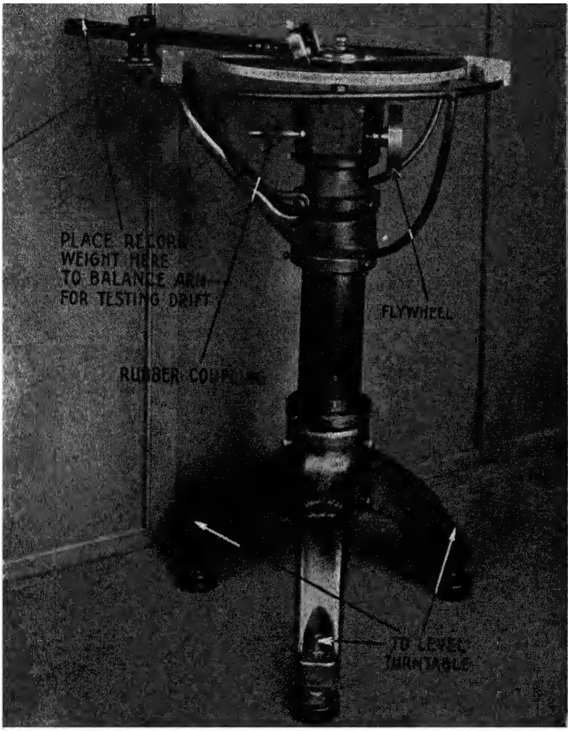

FIG. 32.—Royal Amplitone standard-type synchronous-disc pedestal, showing flexible coupling, flywheel, balanced reproducer arm, and adjustable bolts for leveling.

happens early in the day before the oil is warmed by the friction of operation. For this reason it is advisable, whenever nights are cold, to turn an electric heater against the dash-pot under the Western Electric turntable; or to hang a 150-watt lamp against it in such fashion that the glass of the lamp touches the iron. In addition, it will be well to start the motor before the show at the lowest possible

speed and to let it run at low speed for about 10 minutes before swinging over into the regular operating rate. Similar precautions are needed with oil-damped filters in some other systems.

Causes of Flutter

One obvious cause of flutter is any unsteadiness in the driving motor. This may be due to improper functioning of whatever speed control device is used—a matter to be gone into later. Flutter can likewise be caused by any defect in the bearings of the motor that might cause it to bind momentarily at some one point. Such unsteadiness in the motor can, of course, be detected merely by listening to it, and the remedy is to open up the bearings and see what is the trouble. Misalignment or any other trouble in the coupling between the motor and the turntable can be the source of flutter.

In general, you can analyze the causes of flutter for yourself, in the light of the obvious functioning of your own particular system. Anything that causes the record to move unsteadily under the needle will cause flutter. To find the cause in any given case, you need only go over your gear system, step by step, for all possible sources of such unsteadiness. Starting at the point of the needle, go right down the line of your apparatus, asking yourself at each step, "What is there *here* that could cause unsteadiness in the motion of the record?" Of course, you will go down the line this way more than once. The first time you will look into the surface details, those easiest to get at and examine. You may cure your trouble at the first trial. If you do not, you will naturally go back and start taking the apparatus apart—examining the simplest parts first. This is the most practical method; in the end, if you persist, you are certain to find and to cure the trouble. The very first step, of course, is to try another record, a number of other records, or a test record if you have provided yourself with one, to make sure that you are not wasting effort looking for something that is in the recording.

Flutter and Hunting

The difference between flutter and "hunting"—"weaving"—of the pitch of sound, is the difference between a jerky motion and a comparatively slow, gradual increase and decrease of speed. The ear cannot possibly confuse the two. There are very few causes of flutter that can also cause hunting. Causes of flutter are much more numerous.

A person can easily teach himself what hunting sounds like. On your phonograph at home, or in the theatre (not during a show), if either your synch or non-synch systems allow, try changing the speed of any musical record. You will find that the pitch of the music changes with each change of speed. If the record moves faster, the swings of the needle will follow each other more rapidly—the *frequency* of the vibration will be higher—and the pitch will be higher. If the record moves more slowly, the swings of the needle will follow each other more slowly—the pitch will be lower. If you change speed neither too quickly nor too gradually, the change in pitch will be accompanied by a sighing or groaning effect. This is sometimes slangily termed "wows."

Weaving occurs where the pitch is changing constantly; in other words, where the speed is changing constantly. If the changes are small and jerky, there will be flutter; if they are larger and slower, there will be weaving. Weaving is very annoying, but, fortunately, rather rare.

The Reproducer Arm

The turntable, then must be level in every direction; and it must rotate with absolute steadiness and regularity. But a needle and a reproducer ("pick-up," "sound-box") are also needed to extract sound from the record. Before we examine the needle; let us consider the reproducer arm—the strip of metal that carries the reproducer.

The reproducer arm is simply a mechanical support to keep the reproducer from falling to the floor. It is *not* a device that guides the needle along the record. The sound

groove should do this guiding. When the reproducer arm attempts to do it, sound is very likely to stop without warning.

The reproducer arm is mounted at one point only, and is so mounted that it pivots from that point. There are usually ball bearings in the pivot which allow the arm to swing very freely. It must swing freely if the weak, shallow grooves are to guide the needle unmolested. If the bearings work stiffly, the needle will try to break down a groove and stay right where it is.

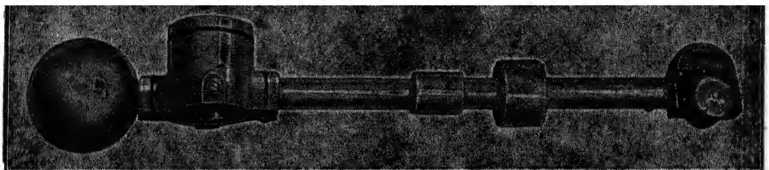

FIG. 33.—Pacent standard-type reproducer arm, showing sliding weight for adjusting needle pressure. The reproducer is oil-damped.

But more than easy motion is required of the reproducer arm. It swings in an arc; that arc must be perfectly horizontal. Most reproducer arms are so designed that a spirit level can be laid across their top at right angles to the direction of the arm. Others are so arranged that they can be counterbalanced by any small, compact weight.

When the counterbalance test is applied the reproducer should have "zero drift," that is, hanging free in air, it should have no tendency to drift in either direction. Some reproducer arms allow both tests. Both should be applied.

Reproducer Drift

If the reproducer has any drift, there exists another condition that may cause the needle to skip grooves or to break them down. Here again gravitation has a chance to pull at the reproducer, and again, this condition, when not serious enough to cause definite trouble, will still tend to create excessive surface noise.

The remedy is to adjust the mounting from which the arm swings. Many turntable systems have these mount-

ings arranged for such adjustment. Some do not. With the latter the projectionist will have to use some ingenuity. However, unless the reproducer is guided by no other influence than the convolutions of the groove in which it moves, trouble will result.

The Pivot Location

In a well-designed system the location of the pivot need trouble no one. But some apparatus still in use is not well designed, and may need a little redesigning. In other cases a reproducer is used (perhaps because it was found to give better quality) which was not part of the original equipment, and therefore does not fit well mechanically.

The reproducer arm must be so mounted that the needle, when swung inward, touches the protruding shaft at the

Correct Adjustment — Incorrect Adjustment — Incorrect Adjustment

Fig. 34.—Sketch showing correct and incorrect location of reproducer-arm pivot. A latitude of not more than one inch is permissible.

center of the turntable. Perhaps the reproducer will not swing inward that far. This does not matter. The point is that the shaft should be in line with the arc the needle describes as it crosses the record from one side to another.[1] A glance at the drawing will make the reason plain. When the proper adjustment exists, the grooves slide under the needle practically as if they were so many straight lines; the effect of their curvature is almost nil. With any other adjustment the curvature reacts upon the needle, causing excessive friction against the outside wall; and, if the mis-

[1] A tolerance of not more than 1 inch is allowable in this adjustment.

adjustment is very bad, the friction will be strong enough either to break down a wall or to throw the needle out of the groove.

The Needle

As for the reproducer itself, the work of this piece of equipment naturally starts at the point of the needle. If the point of the needle is too blunt, it will not fit perfectly into the groove, it will not give perfect sound, and it will set up excessive needle noise. Because it does not fit fully into the groove, it will take advantage of any slightest tendency toward the improper conditions previously described to jump a groove; it will jump on much less provocation than a sharper needle will. Every needle should be examined under a lens before it is placed into the cup for needles that are fit to use. The needles of a manufacturer whose product shows a high percentage of rejections on this test should be replaced by needles of better quality. The needle should never be used twice. It wears blunt during the first use; it is made to do so, in order to prolong the life of the record.

Ten Questions

1. Pick-up needles frequently jump the groove. Name two causes for this, and the remedy for each.
2. Music is harsh—sour. Voices are unpleasant. On sustained notes the music of all singers and instruments is tremolo. If you were trying to explain this condition to your service engineer over the telephone, what name would you give it?
3. Referring to the trouble in question 2, what condition of the turntable could account for it?
4. What conditions in the connections between the turntable and the driving motor could account for it?
5. Roughly, what condition in the motor itself could account for it?
6. One machine has an abnormal amount of surface noise. What is the first thing to do to cure this condition?
7. What are the second and third methods to use?
8. Music is continually shifting in pitch—first it is sharp, then it is flat. What would you call this condition in explaining it to your service engineer over the telephone?
9. Name two causes for this condition.
10. How can you determine which brand of needles is best for your use?

Ten Answers

1. Turntable is off level. Level it with adjusting screws provided for that purpose. Reproducer arm has too much drift. Reduce drift to zero by leveling arm; by placing spirit level across it at right angles to its length. Test drift by balancing or tying back reproducer so it can swing freely.

2. Flutter.

3. Felt or velvet covering of turntable worn smooth, allowing record to slip irregularly under the needle. The clamp holding the record is not firmly in place.

4. The rubber couplings are stiff with age; they no longer filter out motor vibration. Gears are worn or chipped and transmit motor power irregularly. Mechanical filter is defective.

5. Bad bearings, lack of lubrication, brushes fitting very poorly—any condition that will cause or allow the motor to rotate jerkily.

6. Check needle condition; change needle and examine holder to determine if needle is meeting record properly.

7. Check turntable level and reproducer arm drift to make sure no excessive needle friction is due to poor adjustment here.

8. Hunting, or weaving.

9. Defect in motor speed control or motor itself causing or allowing fluctuation in motor speed. A set-screw loose and slipping, or similar mechanical defect between the motor and the turntable allowing fluctuation of turntable speed.

10. With a lens examine a number of specimens of several makes for smooth and sharp points; reëxamine after playing for evidence of wear. Count rejections and choose the make that shows the smallest number. *All needles so tested should previously have been approved by competent authorities as capable of good reproduction of all frequencies of sound. Consider no others.*

CHAPTER V

BETWEEN THE PROJECTOR AND THE AMPLIFIERS

Before going on to the main amplifier, and its action, it will be necessary to deal in greater detail than we have, as yet, with the coupling devices between it and the reproducing arrangement mounted on the projector.

The most important of these is the means used to couple the photo-electric cell to the output circuit. In many cases the current passing through this cell is extremely minute. If leads from such a cell covered any great distance the current would be practically lost by capacitative action.

Capacitance

Two metal plates arranged parallel to each other, but prevented from touching by some sort of insulation between them, represent capacitance. A device of this kind is called a *condenser*. We shall consider condensers again in another chapter. For the present we are only concerned with the fact that when connected across a line they will smooth out the irregularities of fluctuating direct current. And what is true of two parallel plates is also true of two parallel wires.

What takes place in a condenser is this: when it is connected across a direct current circuit, electrons will flow into the plate connected to the negative side of the circuit and will "charge" it. Accordingly, there will be a voltage difference across the two plates—a difference of electronic pressure—which is similar to a difference of steam pressure. The condenser has "stored up" power, so to speak. If the wires were disconnected from it the charge would still remain, and could be drawn off by short-circuiting the plates. (In a large condenser it would be drawn off with

a rich spark, and a distinct shock to the man who put his hands in the way.)[1]

Now if the direct current voltage is fluctuating, a decrease in voltage would have the effect of partially discharging the condenser. It would draw off as much of the charge as would reduce the stored voltage across the plates to equality with the applied voltage. Conversely, if the direct current voltage were to increase it would increase the voltage of the charge, and thereby lose some of its own power. A condenser sufficiently large will thus smooth out irregularities in any direct current.

Capacitance in Photo-cell Leads

But it is rather obvious that a pair of parallel wires is the same thing as a condenser, except that its capacity is much less. Now the fluctuations in potential across a photo-electric cell are extraordinarily small. But these fluctuations represent the pick-up of the sound recorded on the film—they are all that there is of that sound at that point. Later on, after they have been amplified a hundred million times or thereabout, they will be strong enough to set the air in a large theatre vibrating with Maurice Chevalier's wit, but just at their beginning they would not fill a thimble. Now if the circuit from the photo-electric cell were led any great distance, the sound fluctuations would be so smoothed out by capacitative action that no known amplifier could pick them up. Even if the wires carrying them were purposely run other than parallel this would happen. For the wires would have to be run in some sort of conduit or shielding; if they were not, all kinds of stray charges would be picked up. Many might be much stronger than the photo-cell currents, and all that the audience would hear would be noise. On the other hand, with shielded wires the sound would be lost in charging the conduit. In short,

[1] A bolt of lightning is only such a spark from a cloud which has been charged at opposite potential to the earth by condensation of water vapor and the friction of the wind; possibly, also, by the action of sunlight.

photo-cell power often has to be used right where it is created; there is not enough of it to go further.

The Photo-electric Cell Amplifier

This is not the case with all types of cells. Some can be coupled to a transformer, and the output of this may be led some distance to an amplifier. Others need to have the amplifier immediately beside them. In such cases the amplifier is nearly always mounted on the projector base and becomes part of the projector assembly.

In an amplifier of this kind the cell output may be multiplied a thousand or fifteen hundred times, after which it is strong enough to be transmitted. But this amplifier may be part of the projector assembly, and the projector assembly vibrates. If the amplifier should vibrate also, small changes in the capacitance between different parts, and between such parts and the surrounding casing, might take place. Also, some of the elements inside its vacuum tubes might begin to vibrate at their own natural rate of vibration. It would take very little of this to create much more noise than the photo-cell current does.

Therefore such amplifiers are protected against vibration. Commonly, they are suspended from springs. Sometimes they are so mounted that they can be tilted with the projector. When they are mounted in this way, their housings must be arranged to allow the amplifier to be shifted till it hangs straight downward; otherwise, the amplifier will touch the casing, and the purpose of the spring suspension is defeated.

The casing of these amplifiers is often mounted on a rubber base, further to defeat vibration. The rubber base may become soaked with oil from the projector and swell; and amplifiers whose housings tilt with the projector angle will then touch their cradle. An amplifier of this kind must hang clear of its surroundings at all times. The springs holding it must be in good condition. Also, tubes, especially small ones, often develop the condition known as

"microphonic." They act like microphones, but not to the extent of picking up recognizable sounds. However, if some element in them—especially the filament—is the

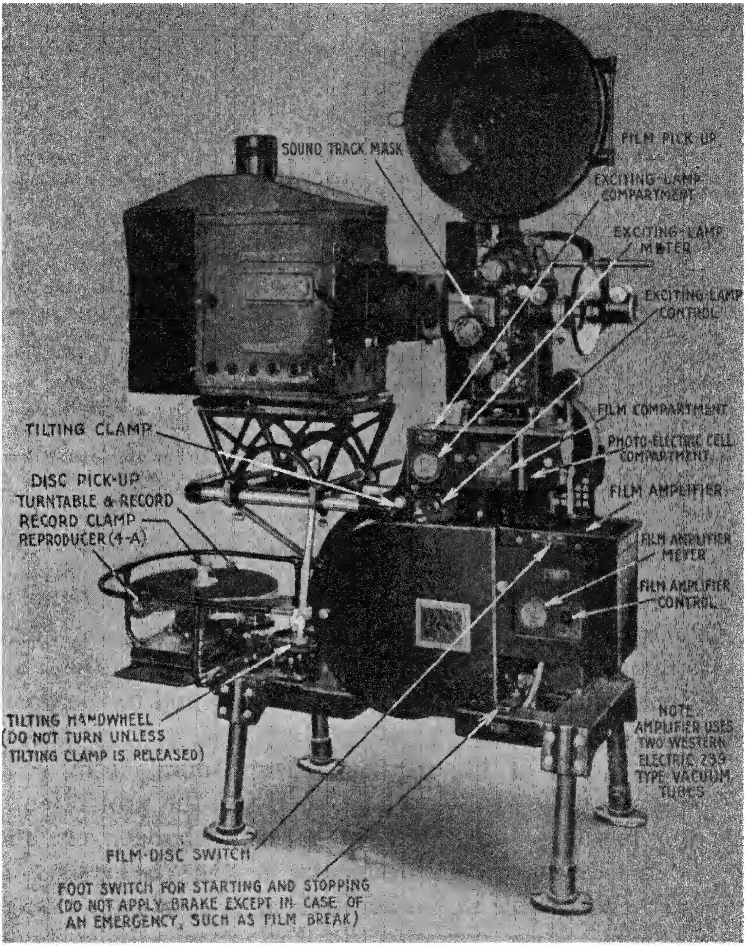

FIG. 35.—Western Electric Universal Base, showing disc turntable and reproducer.

least trifle loose, it will vibrate with the slightest vibration that passes through the spring suspension. Such a tube will introduce machine noise into the sound, in spite of

all precautions. It should be replaced, or at least shifted to the last stage of the amplifier.[1]

Watch Excessive Oil

When the rubber mat swells, it should be replaced. It may, in swelling, so strain the amplifier that some part will become twisted, allowing short circuits or allowing some portion to become loose, and therefore to vibrate. The rubber mat should be kept as clear of oil as possible, in the first place. When, in spite of all precautions, the effects of oil begin to become noticeable, it should be replaced promptly.

Projector noise which is picked up by the photo-cell amplifier is easy to recognize. It sounds like no other trouble. It sounds like what it is—a projector in motion. Even in mild cases, where so little of it is present that the real resemblance is lost, it is readily identified. Nothing else in the system (except a microphonic tube in the main amplifier) has a similar sound.

The Attenuator

After it has passed through the film amplifier, the photocell output is often stronger than sound from disc. The "attenuator," used on many systems, is an adjustable resistance that allows cutting down film sound to the point of balance.

Moreover, it is important to keep sound from both projectors at the same level. Otherwise, the projectionist must remember the difference at each changeover, and make the necessary adjustments, if the changeover is not to be noticeable in the auditorium as an abrupt change of volume. Now, keeping the disc outputs balanced is not very difficult; two reproducers of the same type and

[1] Naturally, anything picked up in the first stage is amplified by those succeeding it. But trouble occurring in the last stage is not. Since these amplifiers may have a very large "gain," a microphonic tube that sounds like thunder and earthquake in the first socket will sometimes prove quite harmless in the last.

make will give about the same output, the magnet strength and number of armature turns being constants, and also the spacing of these elements. But many things vary the film output. The age of the exciting lamp, how dark it has become, the precision of the focus, the condition of the photo-cell and of the tubes in the photo-cell amplifier, the age and condition of the B batteries—a difference between

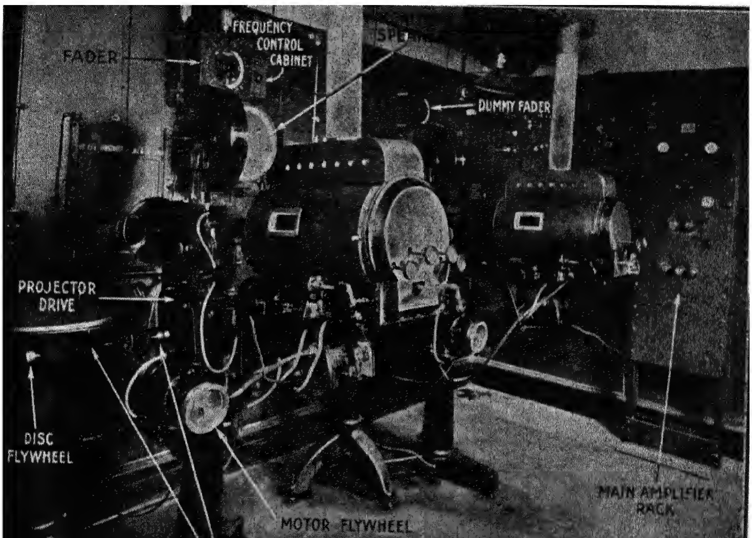

FIG. 36.—Royal Amplitone standard installation, showing fader and its "dummy" mounted on front wall of projection room. Beside the "main" fader is shown the "frequency-control cabinet," a tuned filter adjustable for either speech or music, shown enlarged in Fig. 47. This fader controls both volume and sound changeover.

the two projectors in any of these items means a difference in volume.

It is not economical to throw out a photo-electric cell or a B battery because their output is slightly low; a somewhat darkened exciting lamp may still be fit for further use. Tubes may be a bit weak and still be perfectly good, and so on, the attenuator can be used to compensate for such trifles and to balance the movietone output of the

two machines. When cells, tubes, B batteries, exciting lamps, or slit assemblies are changed, it is well to check the equalization of the machines.

Checking Equalization

This can be done in two ways. One is by inserting duplicate reels and then changing over rapidly, comparing volume. (It is desirable to test the exact matching of the reels by swinging them around. It may be that the development of the two prints differs.) Or a reel with some sound that is very steady in volume—a constant-frequency reel is excellent if one is available—may be run through both machines, and the volume slowly adjusted each time for zero audibility. Comparison of the points on the volume control at which zero audibility was obtained will indicate the attenuator adjustment needed. Simpler than either of these tests is mere continued check on change-overs, which will soon reveal if one machine is noticeably louder than the other.

Film-disc Switch

In general, each projector has a disc reproducer, designed to create sound from phonograph records, and a film reproducer, consisting of exciting lamp, optical train for focusing the exciting light, and photo-electric cell, designed to create sound from a special track photographed on the film. Where either disc or film pick-up is used alone, the switching arrangements are simplified accordingly.

From each pick-up comes a pair of wires, carrying pulsating currents that represent sound. It is necessary to connect either the disc, or the film, output wires to the main amplifier, depending on which system of reproduction is to be used.

This simple matter of switching would hardly be worth mentioning, if it were not for complications that will be explained in a moment. For the present it is clear enough that any double-pole, double-throw switch will answer the

purpose. The pair of wires leading to the main amplifier may be connected to the blades of the switch. The blades may then be thrown either to the pair of clips in contact with the disc pick-up; or to the other pair of clips, in contact with the film pick-up.

Film Pick-up Currents

But this is not the end of the matter. When the film pick-up is in use it is necessary to supply the polarizing potential to the photo-electric cell, and if a photo-electric cell amplifier is also used, which is frequently the case, filament and plate current must be furnished to that amplifier. When disc pick-up is in use it is obviously desirable to cut off these current supplies of the photo-electric cell and its amplifier. Switching arrangements for controlling the current supplies are often combined with the output film-disc switch, so that both changes can be made in one operation.

Two-in-one

Therefore, this one operation covers two functions. For example, in running down the reason why there is no sound from disc, it is sufficient to check the continuity of sound currents through the film-disc circuit of the switch. How this switch performs its other function of supplying currents to the photo-cell and its amplifier is irrelevant in that case. Similarly, in checking a break in the filament supply of the photo-cell amplifier, the action of the film-disc switch, in the matter of selecting either of the two types of pick-up, is irrelevant. Here are two separate jobs often performed by a combination device. It is especially important to remember that these are separate jobs in the case of irregular sound from film, indicating an imperfect but not completely broken connection. In this case it is necessary to remember that the functions performed by one switch (in many systems) can actually be

analyzed into not merely two, but five, separate and distinct duties, involving separate and distinct circuits.[1]

But there are other methods of arranging the film-disc transfer, and of supplying the photo-cell and its amplifier with the necessary currents. A separate switch may be and sometimes is used for each of these two purposes, simplifying the layout.

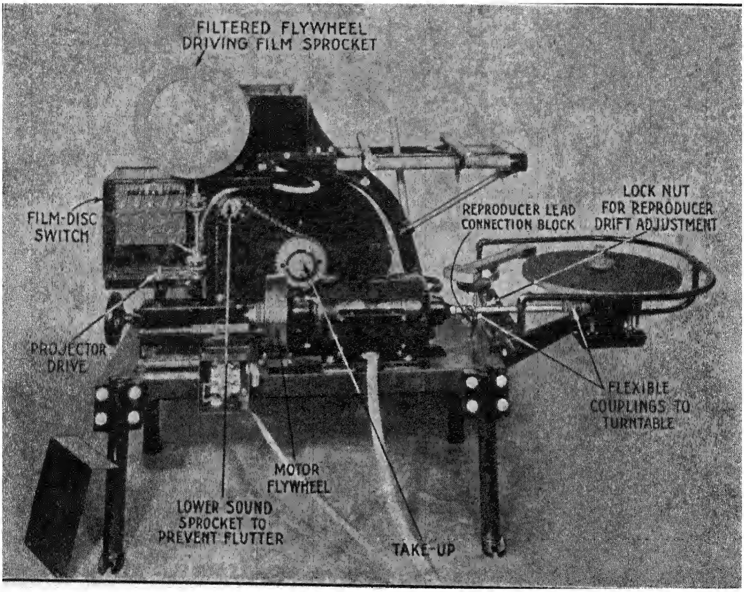

FIG. 37.—Western Electric Universal Base, showing film-disc transfer switch.

On the other hand, some systems use the practice of switching both projectors from film to disc simultaneously, employing a special switching cabinet, which is generally mounted on the wall above the fader. The film and the disc output leads from both projectors (or from all, where more than two are used) are then brought from the projectors to this switching cabinet.

[1] The five are: switching the speech circuits, supplying the exciting lamp, lighting the film amplifier tubes, polarizing the photo-cell, and supplying B current to the film amplifier.

Switching keys, of the type used in a radio set or behind a telephone switchboard, are generally used in these cabinets for compactness, and because the output currents of both film and disc pick-up are small enough not to require switch blades of any appreciable carrying capacity. The internal arrangement may be regarded as two (or more) double-pole, double-throw switches, acting simultaneously, each controlling the speech output of one machine. In some cases such a cabinet may be supplied with low-voltage direct

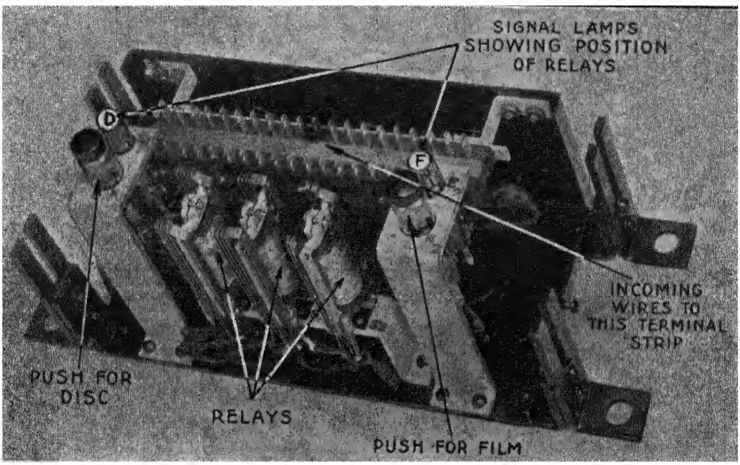

Fig. 38.—Western Electric D 86334 film-disc switching panel, front view, cover removed.

current, and the switching done by relays, the projectionist merely pushing a button.

Where such cabinets are used, supplying currents to the exciting-lamp, photo-cell, and photo-cell amplifier is usually arranged through separate switches, one to each projector.

Your own system may use still a different method; however, in the long run, all serve the same end. In some way they provide for a choice between the disc and the film output of each projector, and thus are essentially double-pole, double-throw devices, one for each machine. In addition, provision is made for supplying or cutting off

the necessary currents for the operation of film reproduction, and the switch that does this is, from the point of view of one projector, essentially a single-throw device (on and off), having as many blades as are necessary for the circuits required.

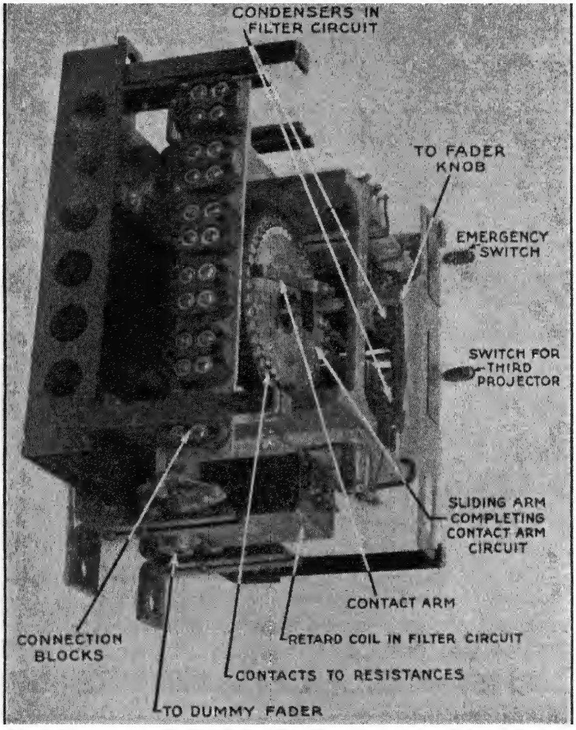

Fig. 39.—Western Electric type 702A fader, which controls both volume and sound changeover.

The Fader

Though we have chosen between film and disc, we are not yet ready to switch our speech current into the main amplifier, because we have not yet chosen between our two projectors. It is often the fader which (because it can perform two functions) enables us to make this choice.

The other function of the fader, in many systems,[1] is to control the volume; and in the interests of simplicity, it may or may not use the same mechanism for both purposes.

Considering the action from the point of view of one projector only, such a fader uses a "constant impedance"

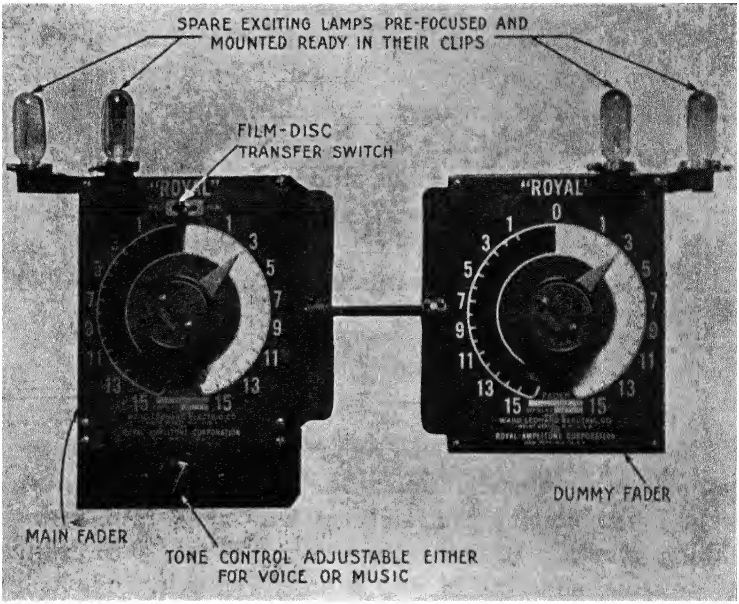

FIG. 40.—Royal Amplitone standard-type fader, showing spare exciting lamps mounted in clips, prefocused and ready for instant insertion if needed.

resistor—a device to be explained later—which acts much like any simple rheostat in reducing the amount of current permitted to reach the main amplifier. There are two of these resistors, one for each projector. If a third projector is used, a switch may be provided to allow this to be "cut in," temporarily, on either of the resistors, and so substitute for one of the others.

[1] Nearly all except R.C.A. In the product of that manufacturer, "fader" is the term applied to the sound changeover device, and the volume control is located elsewhere.

Commonly the resistors are so arranged in a semicircle that twisting a knob connects the main amplifier with either one or the other. Swinging that knob around then effects the changeover.

The construction is such that on changeover the contact arm is swung over through zero volume so that at the instant of change all sound is cut off.

Some systems use a single resistor of this type on each machine, changeovers being worked by throwing a switch.

Many faders also have a "cut-out" switch, which eliminates the variable resistance from either circuit and cuts in, instead, a fixed resistance of a definite value. This switch may be used in case of fader trouble, and since it cuts the rest of the fader out entirely, the show may be continued while repairs are being made. However, the volume may have to be readjusted at a "gain control"—if there is one—elsewhere in the system.

Fader Trouble

In care, these switching devices chiefly need attention to cleanliness. A projection room is not, at best, a scrupulously clean place. Among the worst of its difficulties is carbon dust, coming from the arcs, which sifts into the most hidden places. It leads to peculiar effects with sliding or pressure contacts of any kind. The telephone transmitter, and the microphone which is probably used in your announcing system, are chiefly a "button" filled with carbon dust, and depend for their operation on the principle of the varying resistance of carbon dust under very slightly varied pressures—such variations of air pressure as may be produced by the waves of a human voice. Now if carbon dust is substituted for metal-to-metal contact in a fader or film-disc transfer switch, a gratuitous and unwelcome microphone has been added to the sound system, with resulting noises. The unintended microphone will not work exceptionally well; it cannot be relied upon to reproduce all frequencies faithfully, but it will create a number of crackling, snapping, clicking or paper-tearing sounds with joy

and enthusiasm. Carbon tetrachloride (or Carbona), which is the same as the liquid in the current-proof fire extinguisher to be found in projection rooms, is the best thing to use for cleaning; it cleans readily, dries quickly, and does not corrode.

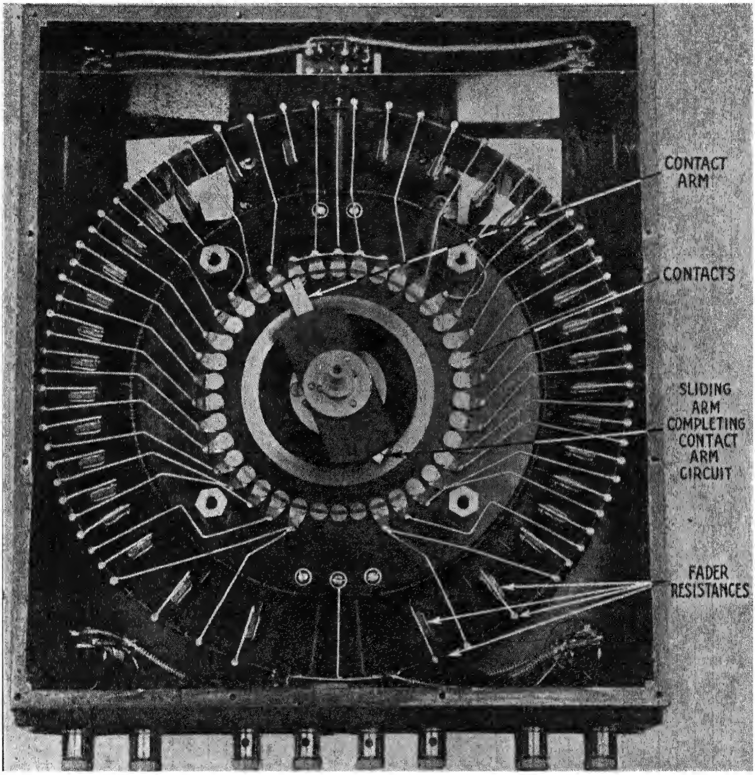

FIG. 41.—General Radio type 398 fader, used in some Western Electric systems. It controls both volume and sound changeover.

Keeping the fader clean is a sure way of preventing fader trouble. If after a handkerchief is run over the contact points a black spot shows on the linen, the fader needs another bath. After the bath a very thin coating of vaseline—*very* thin, a film, not a thickness—will prevent friction and cutting of the contact points. The film can not be

made too thin. Use only vaseline enough to cause the contact to feel slick to the touch, never enough to be seen.

Still More Switches

The sound current feeding out of the fader may or may not reach the main amplifier at once. If non-synchronous

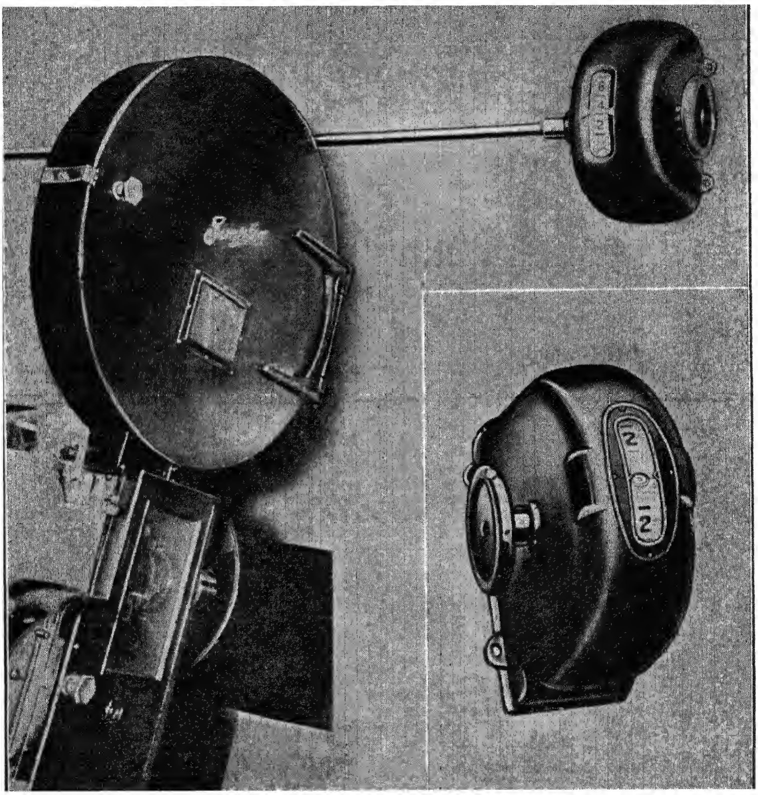

Fig. 42.—Pacent standard-type fader, controlling both volume and sound changeover.

or microphone announcing devices are incorporated into the system, switches which allow these to be substituted for the synchronous pick-up will generally be placed, electrically, between the system amplifier and the fader. The non-synchronous will have its own volume control, and the

microphone needs none, the announcer's control over his own voice being sufficient. However, the "gain-control," which governs overall volume in some systems, may have to be reset for these auxiliaries; and some switching panels of this kind include a rheostat permanently set for proper microphone volume.

Auxiliary Equipment—The Non-synchronous

The non-synchronous device generally consists of two turntables, each electrically driven, and a changeover

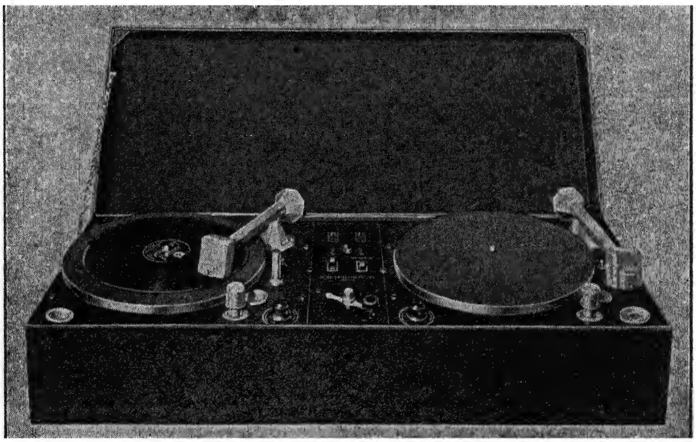

Fig. 43.—Pacent standard theatre-type non-synchronous double turntable, equipped with volume control and fader for changeover between discs.

switch between them, which often is also the volume control. The same type of disc reproducer that is used for synchronous pick-up is employed. Levelling the arm presents no trouble, for it is permanently mounted, but the non-synchronous cabinet as a whole must be level. There are no mechanical vibration filters since small motors running with satisfactory smoothness are used, and the records give less trouble—the grooves do not need to be crowded to accommodate a full reel of sound on one disc. Electrical filters and equalizers, however, may be employed.

AUXILIARY EQUIPMENT—ANNOUNCING

Microphones used for theatre announcing are practically always of the carbon button type. They consist of a pinch of carbon dust between two metal plates. One of these plates is free to vibrate with the air vibrations of the speaker's voice. A low-voltage direct current, such as 6 or 12 volts, passes through the carbon dust. The change in the pressure of the vibrating disc against the carbon dust varies the resistance of the arrangement and consequently modulates—varies—the microphone current at the frequency and volume of the speaker's voice.

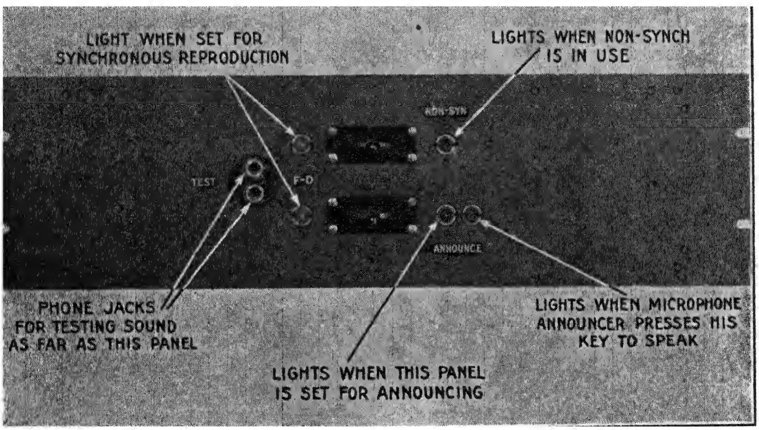

FIG. 44.—Western Electric type D 88449 switching panel for synchronous and non-synchronous reproduction, and for announcing.

SWITCHES HELP IN TRACING TROUBLE

Because these switching circuits, between the various types of pick-up and the amplifier, may occasion some confusion in running down trouble, it is well to have their essential relationships clear. The trouble they may create is more than compensated by the help they give in locating trouble. They can often isolate a difficulty immediately, locating it in one type of pick-up or on one projector, and the work of finding it is then immensely shortened. If the trouble is found on all types of pick-up, the main

amplifier must be at fault, and no time need be lost in searching elsewhere.

If the trouble in question is found on all synchronous but not on non-synchronous sound, the synchronous fader output (not the input to the fader, or only one machine would be involved), or the synchronous side of the synch-non-synch switching panel, is at fault.

This is matter for more detailed discussion later, when the shortest methods of running down and curing troubles will be considered. Meanwhile, it is well to stress the importance of understanding these linking circuits in the particular sound system the reader may have to deal with.

The outline of these circuits, as used in some of the more popular types of sound systems, is all that has been described here, or could be, in the nature of things. It is believed that the reader will find this outline useful as a guide. It will in no sense replace detailed study of the layout with which his own particular projection room meets the necessities involved. But that subject will be treated more thoroughly in another chapter.

Ten Questions

1. What is the chief preventive of fader trouble?
2. What is the chief preventive of sound switching trouble?
3. What is the chief function of the film-disc transfer switch?
4. What other function does it sometimes perform?
5. What is one function of the fader?
6. What other function may it perform?
7. What is the function of the attenuator?
8. Why does non-synchronous give less trouble than synchronous disc reproduction?
9. What is the principle of microphone action?
10. How can the switching arrangement of a sound system help in tracing down its troubles?

Ten Answers

1. Cleanliness.
2. Cleanliness.
3. To feed either disc or film pick-up into the fader.
4. Connects the battery supply to the film pick-up simultaneously with connecting that pick-up to the fader.
5. Control of volume.

6. Changeover between projectors.

7. Balances sound-on-film volume as between projectors. Balances sound-on-film volume with sound-on-disc volume.

8. Sound grooves are less crowded. Motors are smaller and often simpler, and coupled solidly through gears to the turntable. The device is manufactured as a unit, and need only be placed on a level table, no other adjustments required.

9. That carbon dust has less electrical resistance when compressed than when loose. The degree of compression existing in a small amount of such dust is varied by a diaphragm so mounted as to be free to vibrate with the air vibrations of sound.

10. By indicating almost instantly the portion of the system that is giving rise to the difficulty.

CHAPTER VI

AMPLIFIER AND RECTIFIER APPARATUS

Having traced our sound current from its source in the pick-up, whether film or disc, through the fader and the various selecting switches, we are now prepared to see how it is amplified.

Our eyes tell us that the amplifier consists of a box or panel, having some vacuum tubes as part of its equipment and a great many pieces of apparatus inside. We know that the sound current enters the amplifier through one pair of wires and leaves by another, and that while it is inside it is in some way greatly strengthened.

To understand this rather unusual electrical phenomenon, let us first look at some of the internal parts. We can start with one called a choke coil. Under its casing and protective sealing compound, it consists of a great many turns of wire, wound on a metal core.

Now it is only a few years since the discovery of electrons, and the knowledge that the flow of these tiny particles in a conductor constitutes an electric current. Before that discovery, even though no one knew the nature of electricity, electric currents and voltages could still be measured very accurately, by their effects.

Today the magnetic "field" is in the same position that electricity occupied a few years ago; its existence is certain, its strength can be measured, the "lines of force" that compose it can be counted, but nobody knows what those lines of force may be. The greatest of the physicists who weighed and measured the electron, and determined the force of its charge, calmly tell us that the matter of fields and lines of force must remain for the next generation to investigate. Some of them even go so far as to say that this investigation will reveal the electron itself to be a

fiction, the mere mathematical point at which lines of force converge. This involves considerations that we had best leave for the next generation to worry about. What science tells us at present is that electrons exist, and can be weighed and counted and their electrical "charge" ascertained; that lines of force constituting "fields" exist, move with a moving electron, that they can be counted and the strength of their charge measured; and with this

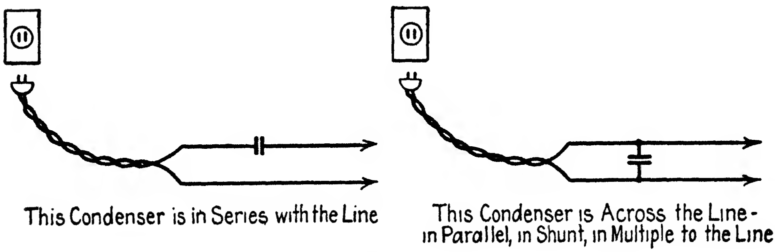

Fig. 45.

we must be content. Present-day theory is adequate for full "understanding" of what happens when certain wires are connected in a certain way, to the extent that it is possible to design and construct circuits, repair them, and predict in advance what will happen with any change in design.

Now let us see what theory says about choke coils.

Lines of Force

An electron is surrounded by "lines of force." An electron in motion carries these lines of force with it. Moving lines of force constitute a "magnetic field."

The magnetic field of an electric circuit acts exactly like the field of any steel magnet. This can be proved by bringing a compass near any wire carrying electric current. If the current is direct (flowing in one direction only), the needle will be deflected exactly as it would be if it were brought near a magnet. If the current is alternating, the needle will be alternately attracted and repelled, as the current changes its direction of flow. Since the change in

direction of flow will occur too rapidly for the needle to respond fully, it will be seen to vibrate around a central point—or perhaps it may rotate completely.

Now some force must act on the compass needle to affect it; and this force, acting invisibly from a distance, is the "field," which is composed of "lines of force."

When the switch is first closed, in a direct current circuit, lines of force rise from the conductor and surround it, remaining as long as current continues to flow, and collapsing back onto the conductor when the switch is opened. In the case of alternating current a switch is opened and closed, in effect, at each alternation, that is, the current starts, stops; starts in the opposite direction, stops; starts again in the first direction, and so on. Much the same is true of pulsating direct current, which flows only in one direction, but flows by fits and starts, so to speak—on, off; on, off, etc. At each of these changes, lines of force rise and surround the conductor, or collapse back again upon it.

Inductance

"Inductance" may at this point be defined as the quality possessed by any conductor of emitting lines of force when current is flowing. Any wire thus possesses inductance; the longer the wire, the greater the inductance. If a great deal of wire is concentrated by being wound in a coil, a great deal of inductance is concentrated in a small space. If the coil is wound on a metal core the inductance is still further increased, since soft iron and certain alloys offer a better conducting path to the lines of force than air does.

Now inductance is like resistance; it tends to hinder the flow of current. With direct current the inductance of the circuit does not matter. It is operative only when the switch is closed and opened; once the lines of force are established around the conductor, their strength remains unchanged as long as the current strength remains unchanged. But with pulsating direct current or with alternating current, the effect on the current flowing is more constant and much like the effect of straight resistance;

therefore the term "impedance" is used in referring to the obstacles to the flow of alternating current; impedance including in its meaning the effect of inductance and of capacitance, as well as of resistance.

It is precisely because an inductive winding tends to hinder the flow of pulsating direct currents that it is often called a "choke coil."

Action of an Inductive Winding

Let us examine this action a bit further. When lines of force rise around a conductor the expenditure of force required deprives the conductor of current. When the switch is opened, the lines of force collapsing back upon the conductor *create a current.*

You may have noticed that direct current circuits which include any sort of inductive winding, such as that sometimes used to supply the fields of dynamic speakers, give an abnormally large spark when the switch is opened. This occurrence is often called the "inductive kick," and is due to the momentarily large currents and voltage created by the lines of force collapsing back on the inductive winding.

It is obvious that if pulsating direct current or any rough, irregular direct current is passed through an inductive winding—through a choke coil—the action of the winding will tend to smooth out this direct current—to equalize its strength instead of allowing it to rise and fall. While the current is increasing in strength, the increased emission of lines of force tends to keep its value down; while the current is decreasing, lines of force collapse back upon the winding, creating more current.

Inductance, then may be defined as an influence that tends to keep the amperage flowing constant at all times, within the limits of its power.

To increase the power of inductance to keep amperage constant, lumped inductance, in the form of many turns of wire which are wound on metal cores, is added to circuits where constant current is desired.

The Condenser

Having thus roughly rehearsed the functions and nature of the choke coil, one of the pieces of equipment commonly found inside an amplifier, let us turn to the condenser.

"Condenser," as the name of a type of lens, is a term well known to projectionists, and to theatre managers concerned with projection. Electrical condensers have nothing to do with lenses; they are an entirely different type of apparatus.

As said before, an electric condenser is any two parallel conductors, separated by insulation. A pair of wires constitutes a condenser—a small but often important one; especially in its effect upon photo-electric cell leads.

The "capacitance" of a condenser is increased in proportion to the area of the conductors facing each other across the insulation. In order to get as much area as possible in the smallest space, commercial condensers are often made of many plates of tin foil or other thin conducting substance, connected alternately in parallel. Another way of increasing capacitance is to make the insulation as thin as possible. If it is too thin, of course, the voltage applied across the condenser will break it down. Paper is sometimes used, but paper, except in the product of the most reputable manufacturers, is unreliable because it will not stand heavy voltage. It punctures and allows the condenser to short circuit. For this reason paper condensers are absolutely unsuitable for sound work unless they are very carefully designed for the voltage they must hold. The "bootleg" type should never be used. Mica is much more trustworthy.

In general, then, the condenser consists of plates of tin foil spaced by plates of paper, mica, or some such substance; the first, third, fifth, seventh, and ninth plates of foil, and so on, being connected to form one side of the condenser, and the second, fourth, sixth, eighth, and tenth plates, and so on, being connected to form the other side. The whole is then usually subjected to pressure to decrease the

total bulk as much as possible, and is fitted in some sort of case to serve as a unit.

The "electrolytic" type of condenser, however, has a different construction. Its functions are similar, except that it cannot be used with alternating current.[1]

Take any condenser (you can buy one in a radio store for a few cents) and connect it to a source of direct current. Disconnect it, and the condenser is charged. It can be discharged by short-circuiting the terminals with a screw

[1] The electrolytic condenser is based on a chemical principle still very imperfectly understood by chemists. However, if an aluminum plate is dipped in a solution of bicarbonate of soda, an insulating film will be formed on the aluminum when a source of direct current is connected to the arrangement. The connection must be so made that the aluminum is positive and the solution negative.

As soon as the insulating film reaches sufficient thickness, current will stop flowing, and therefore no further film will be formed. The thickness of the film consequently depends on the voltage applied; the greater the voltage the thicker the film will have to be before current flow ceases.

In this condenser the conductors are the aluminum and the solution. The insulating deposit formed on the plate of the electrolytic condenser has been measured (the figures are not yet definitely accepted) as less than 1/1,000,000 millimeter in depth. Since the capacitance of any condenser increases with increased thinness of its insulating medium, the electrolytic type combines high capacity with small size, light weight, and low cost, and hence is coming into increasing favor.

If voltage should rise when this condenser is in use the film will puncture, and damage to other parts of the equipment may follow, but the condenser itself is "self-healing"—the passage of current through the puncture simply builds up a thicker deposit. This process continues up to the limits of the device, at present around 600 volts. If the voltage drops again, the film grows thinner over a period of time, until it is just a little more than thick enough to hold the voltage applied. These facts have all been discovered experimentally; the reason for them is not definitely known.

If the polarity of the current applied to the condenser is reversed, the deposit breaks down. For this reason the device must be carefully connected according to the polarity indications furnished with it. For the same reason it cannot be used at all in an alternating current circuit. A theoretical form of this condenser has two aluminum plates in the electrolyte, and according to the polarity of the imposed current the insulating film will form on one and break down on the other; in this form the electrolytic condenser has been found practical with low voltages of alternating current but has not yet come into commercial use.

Other metals than aluminum can be used, and other solutions than bicarbonate of soda. Bicarbonate of soda is not common in commercial forms; aluminum is.

driver or some other conductor. A spark can be drawn if the condenser is large enough, if not, the discharge can be observed with a milliammeter.

Action of the Condenser

Condensers actually store up current; a storage battery does not; it merely undergoes an internal chemical change when current is fed into it, and this change, reversing itself when the storage battery is connected in circuit, *creates* current by chemical action. But condensers store current—free electrons. The battery adds them to a chemical combination—releasing them again on discharge. In the condenser, they remain free and uncombined.

The insulating material plays the most important part in capacitative action. This has been explained by saying that the atoms of this material are "polarized," that is, the component parts of each atom shift out of place. The negative elements, or electrons, are drawn toward one plate and the positive element in the atom, the proton, is drawn toward the other. The shift is merely a displacement; the atom is not torn apart. In addition, the surfaces of the insulating medium, facing each plate, acquire a charge, the potential on one surface inducing an opposite charge of corresponding strength upon the other.

These theories may help clarify the facts of the case—that capacitance is increased if the insulating medium is made thinner; and that different insulating mediums give different capacitance values to the same condenser.

A source of voltage is positive and negative. At the negative end there is a surplus of electrons, at the positive end, there is a scarcity. Voltage may be defined as the tendency of the electrons to correct this inequality of pressure by flowing around the circuit. To say a potential has so many "volts" is simply a way of expressing the extent of the inequality of electrons at the opposite ends of the circuit. To say that so many amperes are flowing is only another way of counting the number of electrons

that are passing in a second, in an attempt to equalize the potential difference.

If the direct current circuit is opened by a switch, there will be a surplus of electrons on the negative side of the switch, and a scarcity on the positive side.

If a condenser is connected across the open switch blades, the plates connected to the negative side will naturally be in the same condition as the negative side of the switch itself; they will promptly be crowded with free electrons, and there will be a scarcity on the positive plates of the condenser. If the condenser is then disconnected from the source of current, a voltmeter will show a difference of potential across the plates, and this difference of potential can be discharged as a spark by short-circuiting the terminals.

"Banks," or groups, of condensers, often used in sound amplifiers, may store up considerable power which they

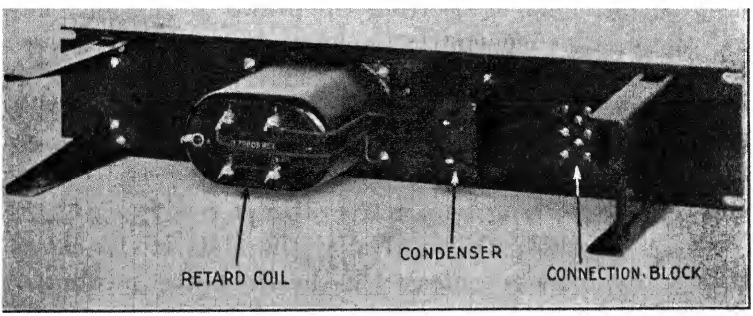

FIG. 46.—Western Electric D 85128 equalizer, consisting of an inductance and a condenser, used in older-type systems to filter out needle scratch.

will retain, if they are in a direct current circuit, after all switches have been opened. Anyone handling them in reliance on the fact that he has "killed the board," is liable to find himself suddenly sitting on the floor a few feet away. For safety's sake no large condenser bank should be touched until the charge has been drawn off by short-circuiting. A screw driver with a well-insulated grip will do for this. Drawing *one* spark is not enough. There may be several

groups in series and all must be discharged. A large condenser, like a gun, is "always loaded."

If the condenser is connected across a line carrying a fluctuating direct current, we may say the negative plates will absorb electrons when the voltage across the line is high and return them to the line again when the line voltage drops below the potential stored in the condenser. This tends to keep the amount of current flowing at a constant value, which, we saw, is the same thing the choke coil tries to do.

Choke coils and condensers are therefore used in combination to smooth out irregular direct current; the chokes being connected in series with the line and the condensers across it. The combination of these two devices is commonly referred to as a filter.

Filter Action of Coils

Let us consider some of the many other uses of these two devices. Let us take the choke coil first.

Because of its nature, the choke coil passes direct current without much difficulty. There is a momentary resistance when the field first builds up as the switch is closed; and there is a momentary increase in current and voltage, known as the "inductive kick," when the switch is opened again and the field collapses back upon the coil. With rough or irregular direct current, these properties of the choke coil tend to smooth out the current flow—to keep the amperage constant.

But the coil may be intentionally designed to present a serious obstacle to pulsating direct current, especially at higher frequencies. An important factor here is the nature of the core, and the speed with which that allows the field to be formed around the wire and to collapse back upon the wire. Coils may be designed for use in filters to stop one band of frequencies altogether. What is true here of pulsating direct current is true also of alternating current, which, in general, has a much harder time with chokes than direct current does. For example, record scratch is sound

having a frequency of about 5,000 cycles. "Scratch filters" are sometimes used in the disc pick-up leads. They may be so designed that the lower frequencies pass through them well enough, but frequencies around 5,000 cycles are stopped. This cuts down the needle scratch. It also, of course, cuts down all musical sounds around the same frequency, such as the distinguishing overtones of many instruments; but if the needle scratch is bad, that can not be helped.

Filter Net-works

Combinations of choke coils and condensers, and often resistances, can be designed for almost any given purpose of filtering. By governing through careful construction the time that the field takes to rise and fall around the coil, and the time that the condensers take to charge and discharge, such filters may prevent the passage of any given range of frequencies. On the other hand, filters may be designed to pass a given range of frequencies exceptionally well, in order to compensate for distortion arising somewhere else in the sound system. Or the combination may be arranged to pass some band of undesirable frequencies unusually well, and, being connected across the line instead of in series with it, used to short circuit these undesirables. In other cases the coupling transformers in the amplifiers, or the windings of the disc reproducer or of the speakers, are so designed that part of their function is that of a frequency filter.

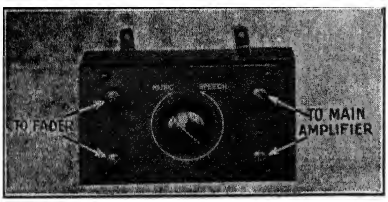

Fig. 47.—Royal Amplitone frequency control, a tuned filter, shown connected in Fig. 36.

Chokes and Condensers Have Another Use

Chokes and condensers have one other use we shall consider here—that of separating alternating current from direct current where these flow through a common circuit.

This happens frequently when vacuum tubes are used, and it may be desired to have the direct current flow in one direction from a common point, and the alternating current along an altogether different wire.

Now we have seen that chokes pass direct current rather well and alternating current rather poorly, and that they can be designed to prevent passage of alternating current or pulsating direct current altogether. Nothing is simpler than to put a properly designed choke in the line in which alternating current is *not* wanted, allowing only direct current to flow.

Condensers Pass Alternating Current

Similarly, condensers pass alternating current, or rather, the effect is the same as if they did. While the current is flowing in one direction, electrons are fed onto the negative plate of the condenser—the plate that is negative during that particular alternation. When the current flow reverses its direction these electrons return to the circuit whence they came, and the other plate receives them and is then the negative plate. An infinitesimal amount of alternating current flows even through an open switch, the amperage being too small for measurement at ordinarily low frequencies. A condenser built for much larger capacitance will allow alternating current to "flow." Its rhythmic charge and discharge will have the same effect upon the circuit as if alternating current were passing through its insulation.

So, just as a choke coil may be used to stop alternating current, a condenser may be used to stop direct current, which obviously will charge it for an instant and will then flow no more. A condenser so used is generally called a "blocking condenser."

Sometimes a condenser is connected across the terminals of a winding, in a case where the same circuit contains both alternating and direct currents; the direct current flows through the winding and the alternating current through the condenser. If the alternating current were forced to

flow through the winding also, its value would be greatly reduced, even if the coil did not act as a high resistance, stopping it altogether. The condenser connected around the coil terminals saves the alternating current this winding loss by "by-passing" it. In such a circuit the capacitance is known as a "by-pass" condenser.

This subject will be very familiar to those already acquainted with the elements of direct and alternating current electricity; to them this treatment will serve merely as a far from exhaustive review. To others it may perhaps seem the most difficult chapter in this book. None the less, the subject will clear itself up considerably when, in the future, we look into the application of these devices to rectifying and amplifying circuits.

The Transformer

For the present, there is one more small piece of mechanism that needs attention. It will be simple enough to those who have followed through so far. Others will do well to go back and read again the explanation of choke coil action. The last piece of apparatus to be dealt with now is the transformer.

In the early days of projection, when a 110-volt direct current supply was stepped down through resistances, the resistance unit was often known as a "transformer." The term was misapplied, according to present-day electrical terminology.

Step-up and Step-down

A transformer, as the word is properly used, is a device for transferring pulsating direct or alternating currents from one circuit to another without physical connection. In addition to effecting this transfer, a transformer will "step-up" or "step-down" either current or voltage (but not both) in the process.

If the transformer steps up voltage, it must cut down current proportionately, and vice versa.

Construction of the Transformer

A transformer may be regarded as two choke coils wound on the same metal core. Sometimes one is wound on top of another. Or the core may be shaped like a square and the two coils wound around opposite sides.

The two coils are distinguished as primary and secondary. The primary is the coil which, according to the way the transformer is connected in the circuit, receives a supply of pulsating direct or of alternating current from the current source. The secondary is the coil in which a corresponding current is "induced" by the inductive action of the windings.

For some purposes transformers are wound with the same number of turns on each coil; for others the secondary has either more or less turns than the primary. If it has more, voltage will be stepped up; if less, the voltage will be stepped down.

If the ratio of the coils is 10 to 1, the step-up of voltage will be 10 to 1, that is, if the secondary has the greater number of turns. If the ratio is 10 to 1 the other way—if the secondary has only one-tenth as many turns as the primary—the current step-up will be 10 to 1, and the voltage correspondingly reduced less than one-tenth. The *power* will remain the same in any case, *less the transformer loss*, which may be small in a properly designed transformer and seriously large in one poorly designed.

Action of the Transformer

But how does the transformer do its work? How is current transferred from one circuit to another without physical connection?

Long ago, in connection with disc pick-up devices, we saw that motion in a magnetic field gives rise to currents in a conductor lying within that field. We may now state more precisely what happens in that case. We can put it this way: Whenever a conductor moves through lines of

force, or whenever lines of force move through a conductor, current is set up in that conductor.

We have seen a number of examples of this—a number of the varying forms of motion than can generate current under these circumstances.

We saw, for instance, that a coil of wire, moving with the fluctuations of a needle playing a disc record, would have a current induced in it corresponding to the motion of the needle, a fixed magnet furnishing the lines of force. We saw that in another form of disc reproducer, the magnet and the wire could both remain motionless, provided that part of the path of the lines of force lay through a piece of metal that did move with the needle. In this case the motion of the metal, which formed part of the "flux path," altered the strength of the lines of magnetic force cutting the coil, and for each alteration in their strength, a current was set up in the coil. The current so set up reproduced in its strength the degree of alteration in the strength of the field, and in its frequency, the frequency with which the field strength had changed; the total result constituting a pulsating current that reproduced in its characteristics the sound engraved on the record.

In the case of the transformer, there is no physical motion at all. The only motion involved is that of the rise and fall of the lines of force, which corresponds to the changes in the alternating or pulsating direct current with which the primary is fed.

This explains why a transformer does not work with smooth direct current. There would be a transfer of energy when the switch is first closed, and another when it is opened again; but as long as the switch remained closed, the lines of force would remain as first formed and no transfer of current would take place.

With pulsating direct or alternating current, the case is different. Lines of force are continually ebbing and flowing through the transformer. Consequently, there is a corresponding current increasing and decreasing in the secondary. Or, we might put this another way by regarding the

primary winding of the transformer as an electro-magnet, which it really is, and the secondary winding as a conductor lying within the magnetic field. Any change in magnet strength will set up, or induce, a current in such a conductor. In this case, the change in magnetic strength is due to the changes in strength of the current that creates this electro-magnet. The strength of the induced currents will be proportional to the strength of the primary currents. Frequencies will likewise be faithfully reproduced, provided, of course, that the design of the device is suitable for such frequencies. (A bad sound transformer is one that has not been designed to reproduce faithfully all the frequencies needed to represent the audible air vibrations we know as sound.)

Transformer Frequency Ranges

The transformer, we remember, may be regarded as a pair of choke coils, and we also remember that choke coils, depending on their design, have frequency preferences. This is even more true of transformers. Unless suitable material is used for the core, the ratio of secondary to primary kept low, and certain other matters of design carefully attended to, changes in the lines of force may find more favorable reception at some frequencies than at others. A power transformer, intended to change the voltage of 60-cycle alternating current, is naturally designed to transfer the greatest possible amount of energy at that frequency; if the action of such a transformer at 5,000 cycles is negligible, it makes no difference, for it is not going to be used at 5,000 cycles. But, on the other hand, a transformer which is meant to handle sound currents in an amplifying circuit must, or should, transfer just as much energy at 5,000 cycles as at 60. Otherwise the reproduction of an orchestra, which uses both of these frequencies, all others in between, and also a few more above and below, would suffer serious distortion. The piccolo might sound louder than the big bass drum, and an audience would call the sound "tinny"; men's voices

might seem high pitched, like women's; or the reverse could happen. All sorts of changes and poor relationships might occur, all coming under the head of distortion. An amplifying transformer, as distinct from a power transformer, should therefore transfer energy, for all frequencies within the speech range, as nearly as possible at the same ratio. None of them is perfect, but a well-designed transformer will come close enough to perfection to satisfy. Of such a transformer we may say that the fluctuations of the primary current, whether alternating current or pulsating direct current, will be exactly reproduced in the fluctuations of the induced secondary current, with strengths at all frequencies very nearly in proportion.

More than two windings may be used on one transformer. Quite commonly in power transformers one primary is used with several secondaries, so that a number of different voltages, for different purposes, may be drawn from the same instrument.

Review

An electron may be regarded as accompanied by a "field," consisting of "lines of force" surrounding it in every direction, and extending for a considerable distance in space. These lines of force move with it when it moves. They are thought by some to be the real substance of the electron, and its apparent weight and size only illusions. If this is true, they are the reality behind all matter, including our bodies.

Lines of Force

The effect of an electron moving in a conductor may be considered as if the electron consisted of lines of force which rise out of the conductor into the surrounding space, remain there as long as current continues to flow, and collapse back upon the conductor when the current flow stops. The number of lines of force surrounding a conductor—the strength of the "inductive field" of that conductor—increases with the amount of current flowing.

Coils

Since the field extends around the conductor for a considerable distance beyond its surface, its strength can be increased, not only by increasing the current, but also by increasing the amount of conductor present in a given area, as, by winding a great many turns of wire in the form of a coil. In the area surrounding that coil there will be more lines of force, a stronger field, than if only a single wire were present.

Inductive Kick

When the field first rises around the conductor it deprives that conductor of current, causing a momentary delay in completing a direct current circuit. When the field collapses back upon the conductor, it generates a current in the wire, causing a momentary increase of current and voltage when the switch of a direct current circuit containing an inductive winding is opened. This is commonly known as the "inductive kick," and may cause a spark which is heavy enough to burn the contacts of the switch.

Cores

The effect of the field may be greatly increased by winding the coil around any of a number of iron or steel alloys, which facilitate the rise and fall of the lines of force.

Choke Coils Choke

The action of an inductive winding in series with a direct current circuit is to tend to keep the current constant at all times. When the current increases some of the increase is immediately used in strengthening the field; when it decreases a portion of the field collapses back upon the winding and generates new current there. Inductive windings are consequently called choke coils, because they tend to "choke" out irregularities in direct current flow.

Frequency Preferences

Alternating currents may or may not flow through such coils, depending on their design, or alternating currents of some frequencies may pass easier than those of other frequencies, again depending on the design of the coil, and on the size of whatever condenser may be in the circuit. The core plays an important part in this; since its nature largely governs the time required by the lines of force to rise and fall, and therefore determines whether or not the field can fluctuate in time with frequency trying to pass. If it cannot, the frequency does not get through.

Filters

Coils designed to choke back irregularities of all sorts are used to smooth out direct current in rectifiers; coils designed to favor the passage of one band of frequencies as against another are used as filters or "equalizers," also called compensators, to compensate for imperfect action of some other part of the sound system. Again they are sometimes used to remove an undesirable frequency, such as that created by "needle scratch" in disc reproduction.

Transformers

The field collapsing back upon the conductor sets up a current in that conductor, or adds to the current already present. A field changing in strength will set up a current in any conductor within its range. If a second coil is brought close to the one originating the field, a current will be created, or induced, in that second coil. At the frequencies used in sound work, the most effective result will be obtained when both coils are wound on the same core. The core may have the shape of a square, and the coils be wound around opposite sides of the square, or wound one over the other on the same side of the square.

Transformers Like Fickle Currents

Current will be induced in the "secondary" coil only when one of the fields, or the core itself, is in physical

motion, or when there is some change in the current strength in the primary coil, that is, the induction will take place only when there is some change in the field strength passing through the secondary winding. This change may be created by moving the secondary winding, or by moving the primary, or by some change or motion in the core that conducts the lines of force, but commonly none of these things takes place. For practical purposes change in the current flowing in the primary is the only change available. Therefore this device with two windings on one core, which is known as a "transformer," can be used only with pulsating direct or alternating current feeding the primary.

Transformers Have Frequency Preferences

As is the case with the choke coil, the transformer, since it is practically a pair of choke coils, may or may not favor some bands of frequencies above other bands, according to its design. A transformer used in a speech circuit should pass equally well all frequencies representing audible sound. A transformer used in a power supply circuit need be efficient only at the frequency of the source of power.

Step-up and Step-down

Depending on the ratio of primary to secondary turns, the transformer may induce a current of higher voltage or of higher amperage, but not both. The voltage induced in a secondary, which has twice as many turns as the primary, will be twice as high as the primary voltage, but the current strength will be less than half as great. No overall gain in power can be had—not until Nature begins to give something for nothing. Transformers designed to convert an alternating or pulsating direct current to one of higher voltage are commonly used in sound systems.

Several secondaries can be wound on the same core with one primary, giving several different kinds of voltage or current from the one instrument. Or a single secondary may be tapped at several points, with the same result.

Warning!

In testing transformers or choke coils for open circuit, a bell or buzzer should **never** *be used.* At least they should never be used on any winding, having a core, which is connected in a speech circuit. Therefore, since there is always a possibility of confusing the speech and power circuits momentarily, they should never be used at all in connection with a sound system. Likewise they should not be used on the windings of a speaker, or of a disc pick-up. The comparatively high currents which are passed by a bell or a buzzer have a magnetizing effect upon the cores, changing their frequency response. A pair of telephones or a *good* voltmeter, devices which pass only relatively low currents, should be used in place of the buzzer. A transformer or choke that has been "buzzed through" may permanently acquire a new frequency preference—a preference that did not previously exist, and that results in distortion in the sound. If a bell or buzzer has already been used on such a winding, the manufacturers of your equipment can tell you what effect may be expected in that particular case, and whether or not the parts in question should be replaced.

Condensers

A condenser consists of two conductors spaced by an insulating material. The greater the area of the conductors and the thinner the insulator, the higher the capacitance of the condenser will be.

Condensers may be charged by any source of direct current, and discharged again by connecting their terminals together, as by short circuiting them with a screw driver. If it is left to itself, the charge will "leak off" slowly. Alternating currents charge and discharge a condenser continuously in opposite directions. The effect is the same as if the alternating currents passed through the condenser. We say these currents can "flow through" it. The amount of alternating current that can "flow through" a condenser depends partly on the size of the

condenser, and partly on the frequency; higher frequencies flow through more readily than lower frequencies.

Condensers as Filters

When the voltage of a pulsating direct circuit increases, some of the corresponding increase in current will be used in adding to the charge of any condenser that may be connected across the line. When the voltage drops again some of the condenser charge will return to the line and help compensate for the decrease in current. Condensers are therefore like chokes in that they tend to maintain a constant amperage in a direct current circuit. However, unlike chokes, they are connected across the line and not in series with it. Condensers are often used in combination with chokes as filters or as equalizers in circuits designed to favor some frequencies more than others; or they may be used alone as filters when the irregularity to be smoothed out is not great, as in the output of a good direct-current generator. Resistances are also used in some of these combinations, and help their action.

Hard or Easy?—But Necessary

To the man unfamiliar with these first elements of alternating current circuits, this chapter, as has been said, will be the most difficult in the entire book, considering not only the past material, but all that is to come. To the man who has even the smallest preliminary acquaintance with those elements, it will seem childish, sketchy, incomplete. The student who finds it tediously simple must be referred to the standard textbooks of electrical theory for further study. Under the circumstances and with respect to the primary purposes of this book, his needs cannot be met more fully here. The student who finds the chapter extremely difficult can only be advised to go back over it again; there is no other choice. Unless he knows just a little about condensers, chokes, and transformers, amplifier circuits will remain a mystery to him forever; when he

learns that little, their commoner difficulties vanish completely.

Ten Questions

1. What precaution should you take to protect yourself against shock, before doing any work on a condenser bank and its associated circuits?
2. If, in tracing down trouble, you find a line with a condenser connected in series, can you tell if that is part of an alternating current or direct current circuit?
3. If a choke coil or transformer seemed unusually hot, what trouble would you expect in the near future, and what steps would you take to prevent it?
4. What might be the effect of a bell or buzzer continuity test upon an inductive winding in a speech circuit?
5. Where should test buzzers and test bells *never* be used in the projection room?
6. What should be used instead?
7. Describe briefly the action of a transformer.
8. Describe briefly the action and purpose of a choke coil.
9. For what purposes are condensers used in sound systems?
10. Can a transformer have more than one secondary?

Answers

1. Discharge them, making sure, if there are a number of condensers, that all groups are discharged. Condensers in comparatively low power circuits are capable of delivering a serious "kick." Use a screw driver with a solid wooden handle, or some equally well-insulated conductor, to short-circuit the condenser terminals.
2. Direct current will not pass through a condenser; therefore, if it is in series with a line, that line is carrying alternating current. The condenser may be part of a filter circuit designed to smooth out a direct current ripple, or it may have some other function in an alternating current circuit.
3. It might burn out; therefore, assuming the part to be properly designed for the place it occupies, immediate steps should be taken to ascertain and correct the cause of the overload.
4. The power of that winding to transmit speech currents without distortion might be impaired, due to the magnetizing action upon the core of the comparatively heavy current drawn by a bell or buzzer.
5. In any part of any speech circuit where there is a possibility that a choke, transformer, speaker, pick-up, or other inductive winding is in the line.
6. A high resistance voltmeter, or a high resistance phone headset.
7. Lines of force rising and falling through the transformer, when the primary is supplied with pulsating direct or alternating current, induce a similar current in the secondary winding.
8. Lines of force rising from it when current strength increases deprive it of current; the same field, collapsing back upon it when the current

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weakens, restores the amperage taken formerly; the overall effect being to keep the current constant. Chokes are used to filter out ripples or other disturbances in direct current; as parts of frequency selector filters or equalizers; or to permit the passage of direct current while "choking back" and prohibiting an alternating current flow.

9. As parts of filter circuits; to permit alternating current to flow while blocking out direct current, or to "by-pass" alternating current around an inductive winding.

10. Yes, it may have several secondaries, each delivering a different voltage; or they may all deliver the same voltage and feed several different circuits; or one secondary may be tapped at different points and thereby deliver several different voltages.

CHAPTER VII

VACUUM TUBES, RECTIFIERS AND AMPLIFIERS

In connection with the photo-electric cell, we found that the "active lining" had the property of giving off electrons under the influence of light. The active lining might be composed of potassium, or caesium, or any of several substances that possess this faculty. All material things being made up of electrons in combination, a number of the physical elements are able to lose some of their electrons, under varying conditions. With certain elements, the impact of light was found to be one condition. With some other elements, heat will have the same effect.

Hot Filaments

If a wire is sealed into a vacuum and is heated by passing current through it, it will give off electrons in rather large quantities.[1] If the wire were heated with a blow torch, the effect would be the same, provided the blow torch could be brought inside the vacuum, in the first place, and could be made to work without air, in the second. The wire would not function as an emitter of electrons unless it were in a vacuum, partly because it would burn, oxidize, and partly because the electrons emitted would simply impart a charge to the air closest by, and would not serve any useful purpose.

Only a slight amount of air leaking into a vacuum tube makes it "gassy" and unfit for use in a sound system.

Cold Plates

Now an ordinary electric light is a filament, or wire, sealed in a vacuum, and therefore it ought to give off elec-

[1] The electronic emission of vacuum tube filaments, that is, the plate current flowing, is very large compared with the emission in most photo-electric cells; but cells, which are much newer than tubes, are fast improving.

trons. It does. The original discovery of vacuum tube rectifiers is attributed to Edison and dates from his early experiments with electric light. That famous inventor sealed a metal plate inside of an electric lamp, with no internal connection with the filament, but with a separate wire leading out from it through the glass. He connected this "plate lead" to one of the filament contacts through a sensitive galvanometer, and found he had a faint flow of current. In other words, he deduced that current must be passing *across the vacuum* of the tube between the filament and the plate, and returning through the outside wire, in series with which he had connected his galvanometer.

Circuit in a Vacuum

We say today that the filament was emitting electrons, some few of which reached the metal plate and constituted a flow of current, returning eventually to the filament circuit through the external connection.

It was next found that a strong flow of current could be obtained through this external circuit by connecting a source of current in series with it, the positive pole going to the plate and the negative to the filament return. Of course, the reason for this is obvious. The free electrons, being always and invariably negative in charge, are attracted by the positive plate in large numbers, causing a heavy current flow. With no positive charge on the plate, many of them return to the filament, and the rest scatter anywhere throughout the vacuum, only a small fraction reaching the plate to form a current in the plate circuit outside the glass.

Rectifier Tubes

In your projection room there are probably a number of tubes of exactly this construction and principle.

For example, if you charge batteries by alternating current, the chances are that you use Tungar bulbs as rectifiers. Some rectifier is necessary to charge batteries from an alternating current source. Otherwise the battery

would charge during $1/120$ second, and discharge again during the next $1/120$ second. With a rectifier, a device that will pass current in one direction only, it charges and stops, charges and stops, with each cycle of the original source, but there is no discharge because the rectifier tube in the circuit will not allow any current to flow the other way, and eventually the battery becomes fully charged.

Rectifier Circuits

You may use rectifier tubes in your amplifier circuit. An amplifier happens to need moderately high voltages of direct current, for purposes to be gone into shortly, and high voltages of direct current are rather hard to obtain. Batteries are not very practical for that purpose; a motor-generator, of course, can be used, and often is, especially in R.C.A. systems, but the most common way involves rectifier tubes. The rectifier is fed by alternating current, which is stepped up through a transformer to the voltage required, and then rectified by a vacuum tube. This process will be explained in greater detail later. The more or less pulsating direct current, which results from the tube action, is subsequently smoothed out by a filter composed of choke coils and condensers, and a high voltage, smooth, direct current is then available for the amplifier. Often amplifier and rectifier circuits are built on the same panel, although they may just as well be separate. Not infrequently, when a number of amplifiers is used, each has its own rectifier unit built in with it.

Rectifier Action

It is easy to see why the rectifier tube passes current only in one direction. Electrons are *emitted* by the filament and are *attracted* by the plate, constituting a flow of current *from* the filament *to* the plate; but the plate, not being itself heated, emits no electrons, and if it did,[1] they would

[1] Sometimes the plate becomes quite hot through being bombarded by electrons, especially in the larger tubes.

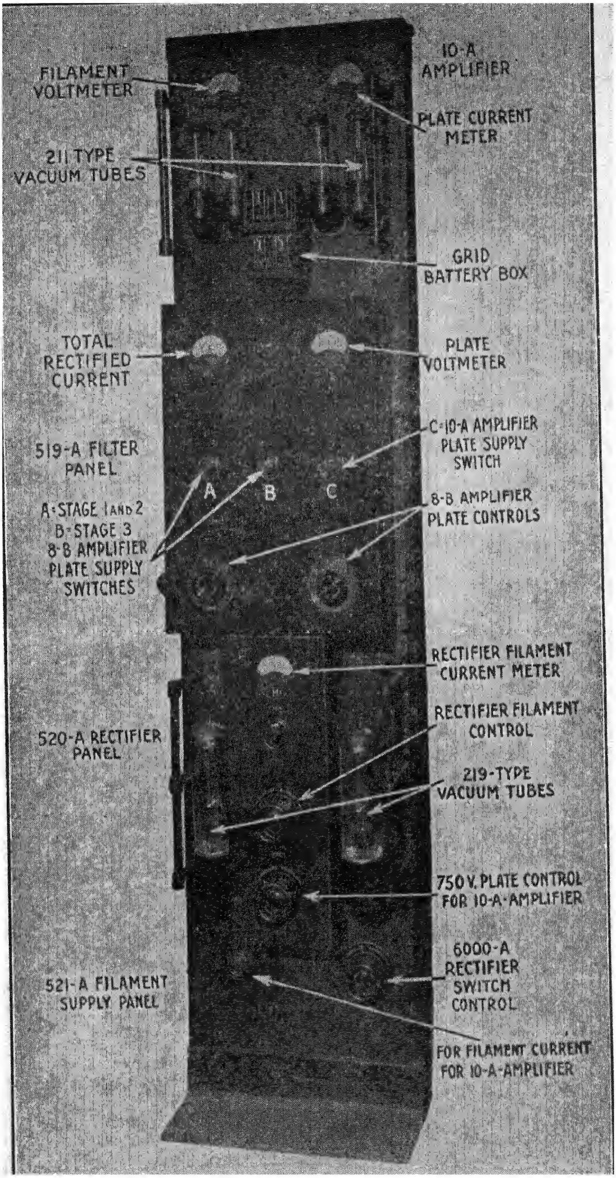

FIG. 48.—One rack of a Western Electric 1S system assembly, showing at top, the 10A power amplifier, and beneath it the 6,000A rectifier assembly, consisting of the 519A filter panel, 520A rectifier panel and 521A filament supply panel.

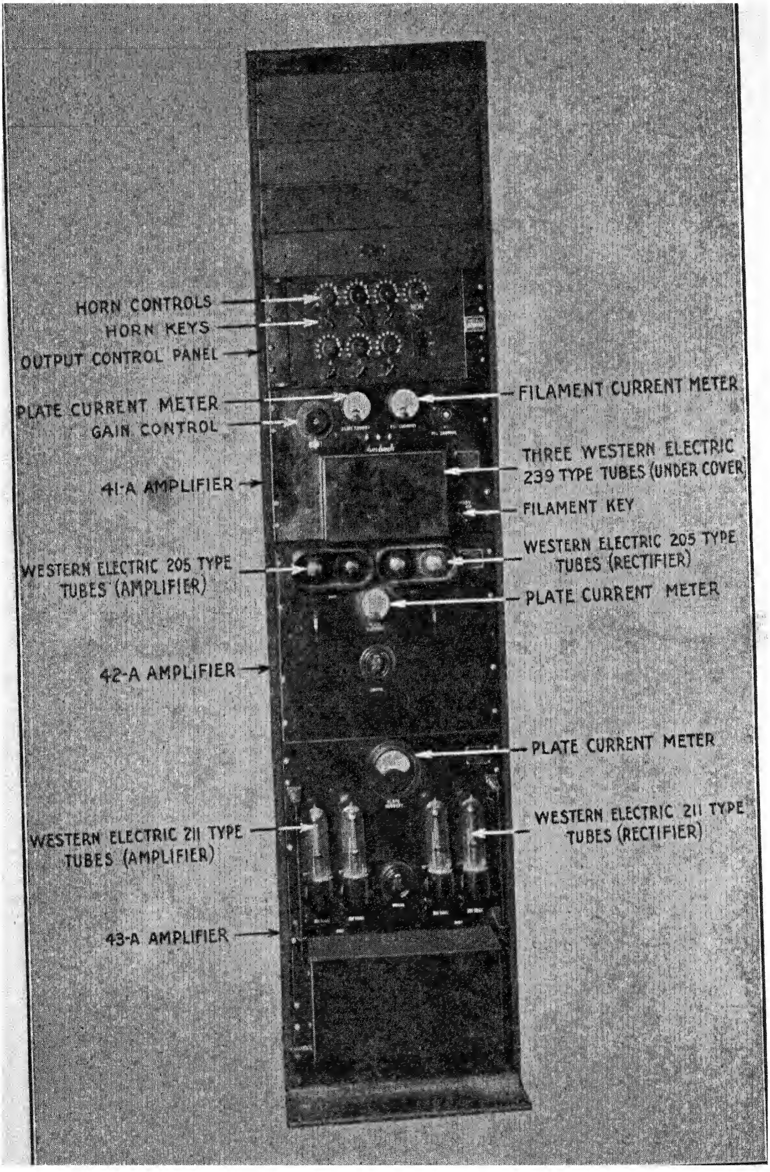

FIG. 49.—Western Electric amplifier rack assembly for 2SX 41 system. The 42A and 43A amplifiers have their own rectifiers built in with them. In addition, the rectifier in the 42A panel supplies rectified current for the use of the 41A amplifier.

not be very likely to go to the negative filament, being negative themselves, but would return to the positive plate. Essentially then, current can flow through the tube *only* in one direction, and consequently current can flow only in *one* direction through any external apparatus that may be connected in series with this filament-to-plate vacuum circuit.[1]

Battery Chargers

Let us consider a typical battery charging circuit, using a Tungar tube as rectifier. We remember that the filament of the tube must be heated by passing current through it, if the tube is to function at all.

In series with the alternating current line is the primary of a transformer, and this transformer has two secondaries. One is the filament secondary, which supplies low voltage alternating current to the filament, to light it, just as if it were an ordinary lamp. The other secondary is the plate supply. We will say one side of this goes to the negative terminal of the battery to be charged, no doubt through some switches and fuses, and perhaps through an ammeter to measure the charging current. From the positive terminal of the battery the circuit continues to the filament of the tube, thence, *through the vacuum* to the plate, and from the plate back to the other side of the plate secondary of the transformer.

With alternating current flowing in the transformer primary, alternating current will be induced in the transformer secondaries; that is, it will be induced if the terminals of the secondaries are connected to some sort of circuit, so current can flow. The terminals of the filament secondary, we know, are connected to the filament of the Tungar bulb, so an alternating current is induced in that secondary at all times when the charger is in use, and flows through the filament, heating it, and causing it to give off electrons. But the plate secondary circuit is closed only

[1] When thinking of vacuum tube action remember *always* that an electric current is really a stream of electrons traveling from negative to positive.

half of the time. It is closed only when the induced alternating current puts a positive charge on the plate sealed in the vacuum. In that case current flows through the battery, causing the chemical changes that "charge" it; continues on through the filament of the tube, across the vacuum to the positively charged plate, and back to the secondary winding. On the next alternation the circuit is still closed as far as the filament of the tube, and as far as the vacuum of the tube; but in the vacuum the negative electrons are repelled by the now negatively charged plate—on the other alternation, therefore, the circuit is opened in the space between the filament and the plate inside the tube, and no current passes.

Mercury Vapor Rectifiers

Mercury vapor tubes, instead of vacuum tubes, are sometimes used for rectifying. The glass is sealed and evacuated in the usual way, but a few drops of mercury are dropped in it before the sealing process takes place. These drops of mercury can be seen clinging to the glass or to the metallic elements, inside, when the tube is cold. When it is heated they evaporate, filling the tube with a purple glow. Mercury vapor rectifiers carry much heavier currents than vacuum rectifiers of the same size, which may be explained as follows:

The free electrons, leaving the filament at high rates of speed, detach, by their impact, electrons from the atoms of mercury vapor. These are also negative and go to the plate like any other electrons. The remainder of the gas atom from which the electron has been taken, being left positive by the lack of one electron, is attracted to the negative filament. The filament, by acquisition of this positive charge becomes that much more positive in charge itself—or that much less negative in charge, to say the same thing another way. The emission of an electron from its own substance likewise leaves the filament that much less negative—less negative by the amount of charge carried by one negative electron (which is a constant

quantity). The effect, therefore, of breaking an electron from a gas atom in the space of the tube is exactly the same as if the regular filament emission had been that much increased—the same on the filament itself, on the vacuum, on the plate and on the external circuits. Gas-filled tubes, in consequence, are capable of carrying much more current, per actual filament emission, than vacuum tubes. They are not now used as amplifiers; on the contrary, the gas introduces complications into the amplifying action, and more than a very small residue of gas generally renders a tube unsuitable as an amplifier. But successful gas-filled amplifying tubes may become common in the future. Many photo-electric cells are now gas-filled instead of being evacuated, with the same purpose of increasing current flow for a given emission. The gases used in such cells are chemically neutral, or inactive.

Amplifying action requires more than a plate and a filament, but we can best approach an understanding of it by giving further consideration to some details, not yet considered, concerning rectifiers.

Plate Potential

The number of electrons emitted by a filament will depend on its construction, age, and condition, and on the amount of current that is passed through it to heat it. But the amount of current that the tube will rectify will be governed, not only by the number of electrons emitted, but also by the positive charge of the plate. The stronger this positive charge is, the larger will be the number of electrons that are attracted to the plate, instead of returning to the filament or being dissipated in the space of the tube—up to the point where the plate is receiving all the electrons that are emitted, and further increase of its potential cannot possibly increase the current flow.

The effect of the plate potential on the "space" current of a tube is very important, both in the action of rectifier tubes and for a consideration of the theory of amplifiers.

Amplifier Tubes Have Grids

Tubes used as amplifiers have another "element" in them beside the plate and the filament. They have also a "grid," a mesh of metal which is placed between the filament and the plate.

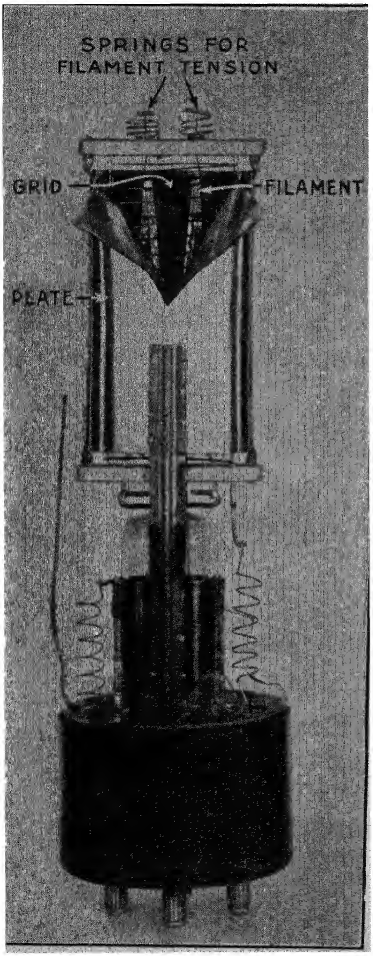

Fig. 50.—Three-element vacuum tube, Western Electric 211E type, glass broken and plate cut away to show all three elements. Used as rectifier and as amplifier.

Amplifier Tubes Have Three Circuits Each

The grid has a circuit of its own. We have seen so far the filament circuit—the circuit that supplies current for lighting (heating) the filament, exactly as an ordinary lamp is lighted. This is frequently called the "A" circuit. Then there is the circuit through the vacuum, between the filament and the plate, with its external apparatus, which is called the plate, and also the "B" circuit. The grid circuit is called the "C" circuit. Batteries may be used for all of these three circuits, which are part of the equipment that must surround every amplifying tube if it is to function. Where batteries are used they are identified as A, B, and C batteries.[1]

[1] In sound work A batteries are sometimes divided arbitrarily into two classes, A and F. Both letters designate filament batteries; the division is

Grid Bias

The grid has a circuit, but no current flows in it. Current flows in the A and B circuits, but no flow is wanted in the grid circuit of an amplifier. To insure that there will be none, the grid is kept at a negative voltage with respect to the filament, by use of C batteries or by the wiring arrangement of the amplifier. By this means the negative electrons are repelled from the grid, and none touch it. If the grid should ever become positive it would simply act like the plate, that is, attract electrons, the return being through its external wiring to the filament. The negative potential of the grid is called its "bias."

Speech Comes In

The speech current to be amplified is connected across the grid and filament. As it rises and falls, or, more accurately, as the speech voltage rises and falls, it alternately adds to or subtracts from the negative bias of the grid. In other words, the negative grid bias "swings" through a narrow range of potential with the fluctuations of the "input" of the voltage to be amplified.

The Grid Swing

Let this be repeated: of the pair of wires which carry the speech voltage into the amplifier, one wire is connected to the grid of the first vacuum tube, and the other wire to the filament of that same tube. As a result of this arrangement the grid bias "swings," fluctuates, with a frequency that is the same, of course, as the frequency of the speech voltage that causes the fluctuation. And the extent, or strength, or "amplitude," of the "grid swing" naturally is the same as the strength, or amplitude, at any given instant, of the speech voltage causing that swing.

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purely one of convenience in cases where two separate sets of filament batteries are used, for different amplifiers in the system. In sound work, also, batteries that supply the field coils of dynamic speakers are often called "H," or horn, batteries.

The Grid Action

Now when the grid is negative, it repels electrons. It is always negative, so it always repels electrons, but sometimes, we have seen, it is more negative than at other times. The grid being negative, the electrons do not touch its wires, but, repelled from them, may slip between them and so reach the plate. Or they may be repelled from the vicinity of the grid altogether, and so return to the filament, which is negative with respect to the plate, but positive with respect to the negative electrons that have left it, and with respect to the grid.

It is obvious that the number of electrons making the complete journey from filament to plate is rather critically determined by the state of the charge on the grid. As the negative charge is increased, more and more electrons are repelled from the vicinity of the grid altogether and return to the filament. As the negative charge decreases, more electrons are able to slip through the grid wires and constitute a current flow across the tube.

Amplification

A tube amplifies because the effect of changes in the grid potential is so much more critical than the effect of the same changes in the plate potential. If the positive charge on the plate were increased by one volt, for example, more current would flow across the tube, because more electrons would be attracted to the plate. But a much greater change in plate current will follow, if that extra volt of positive charge is used to decrease the negative bias on the grid. In other words, the ordinary relationships of current to voltage do not hold in the case of the vacuum tube which is used as an amplifier. If they did, the tube could not amplify. On the contrary, the effect of a 1-volt change in the grid bias is the same, so far as the current passing through the tube is concerned, as that which would be caused by an 8-volt, or a 14-volt, or 22-volt change in the plate potential—depending on the type of tube in question.

Electrons travel through the vacuum of a tube at quite high rates of speed, therefore changes in the plate current follow fluctuations in the grid potential with no "lag" at all, as far as practical considerations are concerned. Consequently, changes in plate current follow changes in grid potential exactly in regard to frequency—and the extent of the changes in the plate current naturally corresponds to the extent of the variations in grid potential. At least this is true when the tube is operated under proper conditions. Therefore, there is no distortion in the tube action; small changes of voltage fed to the grid are reproduced as larger changes in the plate current, with frequencies and relative strengths exactly reproduced.

Overloading

It was said that no distortion occurs when the tube is operated under proper conditions. But there are limits to the power of the grid to affect the tube current. For one case, the grid may be already so strongly biased—so strongly negative—that no small change in its charge can have the proper effect, since only a few electrons reach the vicinity of the grid in any case The reverse condition can also occur. The bias may drop so low that the grid actually becomes positive with respect to the filament, absorbing electrons itself and acquiring an actual grid current; or at least drop so low that a disporportionate number of the electrons from the filament slip through the grid wires to the plate.

These limitations on the amplifying action of the tube show why one tube cannot be used to do all the amplifying that is needed. Amplification is thus extended through a number of stages, the plate current from the first tube being coupled to the grid circuit of the second, and so on, till the desired strength is reached.

C Batteries

In amplifiers using C batteries for bias, an increase of plate current reading will be noticed from time to time, as

these batteries decline in strength. The batteries should be changed long before that increase becomes appreciable. If not, the bias around which the grid swings may have dropped to the point where on extreme swings the lower distortion limit is reached, that is, the point where, on loud volume, the swing carries the grid bias so low, so near to being positive, that it can no longer repel electrons from its vicinity efficiently, and too many pass through to the plate for the condition of the instant. The plate current then no longer perfectly reproduces the grid swing; in other words, the tube distorts.

The Coupling Transformer

In the plate circuit of an amplifying tube, direct current is flowing—not alternating, as in the case of a rectifier—but the strength of this direct current is constantly being varied at speech frequencies by the action of the grid. If a transformer is connected in series with the plate of the tube, the lines of force flowing within that transformer will rise and fall with these fluctuations in current, setting up a corresponding voltage fluctuation in the secondary. This secondary voltage is connected across the grid of the next tube; one terminal of the secondary being wired to its grid and the other to its filament. This secondary voltage is stronger than the fluctuation that operated the grid of the first tube, owing to the amplifying action which has already taken place. Since only voltage and not current is desired, (no current flows in the grid circuit) it can be made still stronger by giving the transformer a voltage step-up ratio. If the ratio be reasonably small, such as 2 or 3 to 1, no appreciable distortion will result from the transformer action, while the effect will be double or treble the overall amplification.

But several other coupling methods, not involving a transformer, may be used. The most common of these employs a condenser for coupling, with resistances in the grid and plate circuits.

The volume of sound represented by the current flowing in any given part of an amplifier circuit, depends, of course, not on the actual current flow itself, but upon the extent of the variations in that flow, the current swing, so to speak. This fluctuating current, fed into the "speech coil" winding of the speaker unit, sets up fluctuating lines of force which operate to move the diaphragm of the speaker forward and back at the frequency and strength of their fluctuation. And the diaphragm of the speaker, alternately condensing and rarifying the air in front of itself, creates sound waves at the frequency and strength of its vibration, the last link in the reproduction of sound.

The Alternating Current Filament

Alternating current tubes require a word. Only a few years ago most tubes, and especially smaller tubes, had to have a direct current filament supply. Let us first see why this consideration applied particularly to smaller tubes.

The smaller tubes are at the beginning of the amplification system. Imagine that a noise—any noise—were introduced into the first tube of an amplification system, and suppose that this noise were half as loud as the sound itself. The noise would be amplified up the line along with the sound, and would emerge still half as loud from the speakers. But suppose that very same noise to appear in the last tube of the amplifying line. By this time the original sound has been so greatly strengthened that the noise would not be half as loud as the sound or anything remotely like that value. In theatre work the amplifying power of a string of tubes may be as high as a billion; the original noise would be absolutely lost and inaudible if introduced into the last tube instead of the first. But what noises are we speaking of, in connection with alternating current filaments?

We are speaking of the noise introduced by working the filaments of a vacuum tube on alternating current—a hum, at the frequency of the alternating current—60 cycles, or 50, or whatever it may be. We know that the grid has a great deal to do with the amount of current that flows

across the vacuum of a tube; we know also that the plate potential has an important voice in the matter. But before either of these factors can have any influence at all there must be an electron emission from the filament, and if that emission varies in strength there will be a corresponding variation in the number of electrons ultimately reaching the plate—altogether regardless of the action of the grid, or of the plate potential. We know, of course, that alternating current starts and stops, starts and stops, so many times per second, depending on the frequency. It does not stop long enough, on commercial frequencies, for the filament to grow cold and dark each time; none the less, the filament naturally does become a trifle cooler with each pause, and a trifle hotter with each renewed flow of current. The alternating current hum that a tube lighted on alternating current introduces into an amplifying circuit reproduces this change in temperature.

Now, though the heat of the filament does change with alternating current as described, it does not change so much in the larger tubes of the last stages that the resultant hum will be heard; for one thing the sound current is stronger in them, and for another they are large enough to store up a good bit of heat in their glass and metal parts, which helps steady the filament and keep the emission constant.. The filament itself is so much heavier it stores up a fair amount of heat without any help. But the smaller tubes do not become very hot, the emission variation is proportionately greater; and hum created there is amplified all along the line.

Small tubes made especially for alternating current use have both a filament and a "cathode." In other tubes the filament itself is the cathode, that is, the emitting element, the negative pole of the plate circuit within the tube. The small alternating current tubes have their filaments coated with an insulating cement, which conducts heat, but not current. Outside of the cement is a coating of "active material"—which may consist of any of the several substances that emit electrons freely when they become heated.

The heat of the filament is transmitted through the cement and heats the cathode, which then serves as an emitter. In order to complete the plate circuit, a lead from the cathode, not connected to the filament, of course, is brought through the base of the tube. Such tubes have five prongs instead of four, and are commonly called "heater tubes." It usually take about a half minute for the heat to penetrate the cement and warm the cathode sufficiently to make it emit.

Review

Let us review briefly.

Any "red-hot"—incandescent—object gives off electrons. Some substances have a special faculty for doing this and do it exceptionally well. Such substances are used in vacuum tubes. They are stretched into the form of a wire and heated to incandescence by passing a current through them. They constitute the filament of a vacuum tube, and the current passing through them is the filament, or A current.

The electrons emitted, being negative in charge, have a tendency to return to the filament whence they came as soon as their initial velocity is used up; but they can be attracted by a positive charge located elsewhere within the vacuum.

Such a charge is supplied to a plate sealed within the glass, and connected with an external source of power. The other side of that external source is connected to one of the filament leads. The flow of electrons across the tube closes this plate, or B circuit.

A One-way Circuit

The plate circuit can have only one polarity, one direction of current flow. If the plate is made negative, the electrons will be repelled from it. The plate, being cold and not of "active" material, does not itself emit electrons. If the polarity of the external source of B supply is reversed—for example, if the external source happens to be an alter-

nating current, which continuously reverses its polarity—current will flow in the B circuit only during the time that the plate is positive. Therefore, the tube acts as a rectifier, converting alternating current to pulsating direct current, current which flows only half the time, but always in the same direction. Such current can be used to charge a battery. Smoothed out by a suitable filter system of choke coils and condensers it can serve as the plate supply for an amplifying tube.

In this way a source of 110 volts alternating current can be used to supply plate currents for an amplifier tube needing much higher voltage of direct current for its own plate circuit.[1] The 110-volt alternating current is first stepped up by a transformer, then applied to the plate of a rectifier tube; the resultant pulsating direct current is smoothed out by a filter. All this apparatus constitutes the unit known as a "rectifier." The rectifier may be built as part of the amplifier it supplies, or may be separate from it. One rectifier, if it has power enough, that is, if it passes enough current, may supply any desired number of amplifiers.

The amount of current a rectifier passes is limited by the amount of current that can pass through the vacuum of the rectifier tube used, to which all the rest of the apparatus is adapted. The amount of current that can pass through the plate circuit of a tube depends on the plate potential and on the amount of electronic emission from the filament. Tubes handling large currents must be large in size, chiefly to dissipate their heat. Very large tubes, not used in sound work, are water-cooled.

The Grid Action

An amplifier tube uses a wire mesh of some kind, called a grid, between the filament and the plate. A third circuit,

[1] Naturally the amplifier tube cannot do its own rectifying. The sound would be cut off half of the time, that is, every time the plate was negative, and an alternating current hum would be loudest thing heard in the theatre. Special "self-rectifying" circuits are known, but they are too troublesome for common use at present.

called the C circuit, keeps the grid at negative potential. This potential is strong enough to repel any electrons that might otherwise strike against the wires, and so set up a grid-to-filament current flow in the grid circuit. But it is not strong enough to prevent the electrons from coming anywhere near the grid; some of them can get sufficiently close to slip between the grid wires and go on to the plate, which is attracting them with a powerful positive charge. If the grid charge becomes more strongly negative, fewer electrons can come close enough to it to slip between its wires, and consequently the number reaching the plate is reduced. This is the same as saying that the plate current is reduced in strength. If the grid charge becomes *less* strongly negative, on the other hand, more electrons can find their way through to the plate, and the plate current is increased in strength.

Amplification and Overloading

If the fluctuating potential of a speech current be used to swing the grid bias, causing it to increase and decrease periodically, the plate current will increase and decrease with exactly the same frequency. The change in plate current caused in this way is much greater than that which might be caused by using the speech voltages to alter the plate potential. Since a small change of voltage in the grid circuit causes a disproportionately large change of current in the plate circuit, the tube amplifies, that is, it reproduces, with much greater strength, the speech fluctuations fed to the grid. No distortion will result if the grid bias be of the proper value, in other words, if the amplifier is properly constructed, and the C batteries, where used, are kept up to full strength. If the tube is overloaded, so that the grid swing is too great, the plate current during the extremes of the swing will no longer accurately reproduce changes in the grid potential and distortion will follow; the tube may even "go into oscillation" and squeal.[1]

[1] A "screen grid" tube permits of higher amplification before it goes into oscillation.

The changes in plate current are coupled through a transformer, or otherwise, to the grid of the next amplifying tube, where they appear, since no current can flow in the grid circuit (the grid being negative, it attracts no electrons), simply as fluctuations of applied voltage. These new fluctuations of speech voltage are exactly the same as those originally created by the disc reproducer, or by the photo-electric cell, or by the announcing microphone, except that they are greater: all of their proportions are preserved. The grid charge of the next tube therefore swings over a wider range of changes in potential and causes correspondingly greater changes in the plate current of that tube. These plate current fluctuations are in turn coupled to the grid of a third tube, and so on, until all the amplification needed has been gone through.

For convenience' sake, in shipping, installing, and replacing, a long train of amplification is split between several "amplifiers," each amplifier being simply a cabinet or panel containing one or more amplifying tubes, with their associated apparatus. The whole may be looked upon simply as one amplifier, since it makes no particular difference whether the next tube in the chain is on the same panel or on another one.

Commonly, but by no means always, an amplification train is so divided into amplifiers that all the tubes of one size are on the same panel, those of the next larger size are in the next "amplifier," and so on. Sometimes each amplifier has its own rectifier for supplying plate current built in with it. Sometimes one large rectifier supplies the current for a number of amplifiers. Sometimes the plate current is supplied from a motor generator, with a filter in the line to smooth out the "commutator ripple," the small irregularities caused by the commutator action of the generator. Sometimes the plate current is supplied by batteries.

At the end of the train of amplification, the plate current of the last tube in the line is fed to the loud speakers, sometimes directly and sometimes through some sort of "horn

control" panel. The fluctuations of plate current in this last tube should still retain perfectly the pattern of the original fluctuations created by the sound pick-up.

Tungar Bulbs

Tungar bulbs are used to rectify alternating currents for charging storage batteries. They handle rather large amperage, but they cannot be used as rectifiers to supply B current to amplifiers, where higher voltages are first obtained by use of a step-up transformer. High voltage would arc across between the plate and filament of a Tungar and break down the rectifying action.

Mercury Vapor Rectifiers

Mercury vapor rectifiers are used to handle higher voltages at fairly high currents. Some mercury is placed inside the tube before it is evacuated and sealed, and this mercury, evaporating with the heat of the filament, fills the space of the tube. Electrons emitted by the filament strike against the atoms of mercury vapor and detach other electrons from their combination within these atoms. These additional electrons go on to the plate just as if they had come from the filament, while the rest of the mercury atom, being now minus one electron, is consequently positively charged and therefore is attracted to the filament. The effect is exactly the same as that of a filament emission much larger than the heat of the tube would ordinarily allow—namely, a much heavier plate current flow.

Three-element Rectifiers

Three-element amplifier tubes are frequently used as rectifiers in rectifier circuits. When this is done the grid and plate prongs of the tubes are connected, not on the tube, but in the socket, and the grid in that case simply acts as a part of the plate.

"Heater" tubes have their filaments surrounded by a cement which conducts heat but not current. Outside

this cement is painted an electron-emitting substance, which is heated, through the cement, when current is turned on in the filament circuit. But no part of the filament current can pass through the cement to the active material. This simply emits electrons because it heats to incandescence. It acts as one leg of the plate circuit, having an additional prong to complete that circuit independently of the filament.

Screen Grid Tubes

Since the three elements in an amplifier tube are metal conductors separated by the insulation of a fairly perfect vacuum, they constitute a double condenser. Any change in the charge, or voltage, on the plate, can induce, by condenser action, a similar change in the charge on the grid. By the tube action explained in this chapter, changes in the grid charge are followed by changes in the charge on the plate. Any 3-element tube thus has a reciprocating relationship, commonly called a "feed-back." At normal values of amplification the condenser action is not strong enough to be important. At extreme amplification it is, and under certain circumstances a process known as "regeneration" is created, and the amplifier "sings" as old-fashioned radios used to. The introduction of a fourth element, a "screen" grid, between the other grid and the plate, offsets the condenser action and prevents regeneration. Screen grid tubes are fairly new. Their adaptation for theatre purposes presents a number of difficulties, and only a few manufacturers now employ them. But, because they admit of greater amplification per stage, some engineers look forward to their increasing use in the apparatus of the future.

Ten Questions

1. How many elements has a rectifier tube?
2. How many elements has the common type of amplifier tube?
3. If an amplifier tube is to be used as a rectifier, what provision is commonly made on the socket in which it is to be used?

4. What is the function of the filament in a vacuum tube?
5. Why is the rectifier tube circuit effective in one direction only?
6. What is the function of the grid in an amplifier tube?
7. Why does the tube amplify?
8. What is the function of the grid bias?
9. What is meant by overloading a tube?
10. Identify the A, B, and C circuits of a vacuum tube.

Ten Answers

1. Two.
2. Three.
3. The grid and plate contacts are shorted on the socket.
4. To emit electrons, when it is heated by passing current through it.
5. Because the electrons travel only from the filament to the plate, not the other way; therefore, the tube offers practically infinite resistance to any current trying to proceed in the reverse direction.
6. To control the amount of current reaching the plate. It does this because the charge placed upon it has a powerful effect on the electrons passing on their way to the plate from the filament. This charge is always negative, and if it is very strong the negative electrons will never approach the grid near enough to slip through its meshes to the plate. As the strength of the negative charge decreases, more electrons will be able to reach the plate. If the grid charge reached zero or went positive, some electrons would reach the grid and set up a flow of grid current, which is undesirable in speech amplifiers.
7. Because the effect on the plate current of changes in the grid charge is much greater than the effect of the same change in plate charge would be.
8. Variation in the grid charge is effected by connecting the grid to one side of the line carrying the speech current which it is desired to amplify. The other side of that line goes to the filament. The grid bias is a negative charge permanently imparted to the grid, which fluctuates slightly under the effect of the fluctuations of the speech potential. This swing in grid voltage centers around the voltage of the bias, which is set at that value at which the tube can work most efficiently and without distortion.
9. The attempt to cram more volume through a tube than it can handle properly. The swing in speech potential supplied to the grid is then so great that at one end of the swing the grid may become positive and, instead of increasing the plate current still further, may actually decrease it by attracting some electrons to form a grid current. Before the other end of the swing is reached, the grid has already become so strongly negative that making it still more so no longer decreases the plate current in proportion. The sound is distorted in consequence.
10. A, filament circuit; B, plate circuit; C, grid circuit.

CHAPTER VIII

SYMBOLS USED IN DRAWINGS—AMPLIFIER CIRCUITS

Every important piece of equipment used in an amplifier has now been examined, but investigating the way these parts work together is a slightly different story. We should have to see them connected in their proper relationships before we could go into that question. Merely to look at the internal parts of an amplifier or at a photograph of

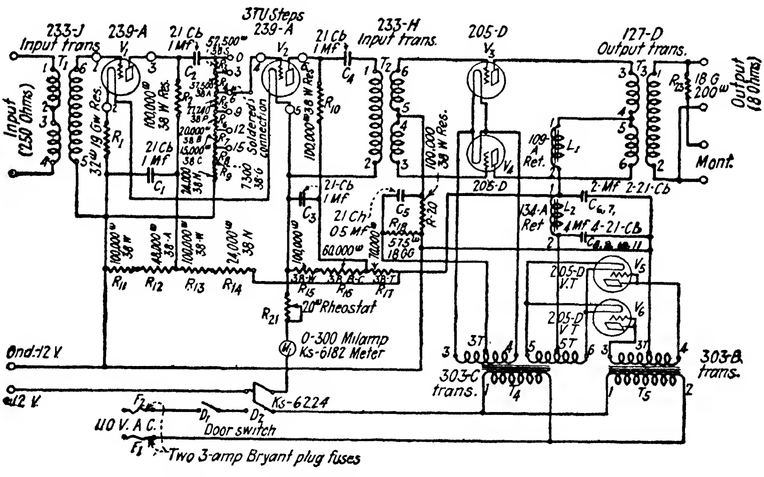

FIG. 51.—Schematic diagram of Western Electric 46A amplifier.

them, would not help a great deal. We would see a great deal of iron, and a great many wires, but it would be an all-night job, in many cases, to trace each of these wires down to find what two points it connects. And by the time a man had finished tracing the last wire, more than likely he would have forgotten about the first one, unless he had made some sort of sketch as he went along.

Now if one were actually trying to follow the wiring of an amplifier in any such fashion, he would be very likely to

make a sketch of that kind for himself. And when he did, he would simplify things. He would not actually draw out a tube, for example. He would sketch one roughly, and since it is the internal elements of the tube that matter, and not the glass, he would sketch the elements and forget about the glass. If one did much of this kind of work, he would soon develop an alphabet of symbols for drawing electrical apparatus quickly.

Such an alphabet already exists, and is listed in the back of this book. But no one wants the trouble of memorizing a list of unusual-looking symbols. The list at the back of the book has been placed there for future reference. Opposite this page is a conventional drawing of a common type of amplifier used with sound equipment, containing nearly every symbol in ordinary use. If this drawing is subjected to a short examination, the meaning of the symbols should become self-evident, and the reader will probably never need to use the list in the back of the book.

Drawings Help in Tracing Trouble

Why is the alphabet of these drawings needed? Because when there is trouble with an amplifier—or any other circuit in the sound system—it takes too much time to trace down the actual wires in order to find out where they go. Sometimes they are twisted around behind some part of the apparatus, and it might be necessary to take half the equipment off the panel to follow them. Sometimes they are combined with a number of others in a cable form. A test with headphones will not help much—the line may have several branches. A drawing, such as the one we have here, shows all the circuits at a glance.

Suppose, for example, you smell insulation burning and see smoke coming out of your amplifier. You will turn the amplifier off in a hurry, and open it up to see what has happened. The first thing you see is that the smoke is coming from a square black part. We will suppose that your amplifier is the one illustrated in the drawing and that

the black part that is smoking is marked with red paint, T_5; also, 303-B transformer.

You have the drawing of this amplifier, the same one that is reproduced here; it is pasted on the back of the cover. (If it has fallen off, get another.) If you can read symbols, you can find T_5, transformer 303-B, in the lower right-hand corner of the drawing; and the next glance will show it to be the plate transformer that feeds the two rectifier tubes. You know that they are the rectifier tubes because the drawing shows the grid and plate shorted together, and therefore they can not be amplifiers.

You now know exactly which wires to follow to find the short circuit that is overloading your transformer, and you trace them with the help of the drawing, which is the quickest way possible. For example, the first thing you see is that the transformer in question connects directly to vacuum tubes V_5 and V_6. Suppose one of these tubes has short-circuited internally. You may or may not happen to remember that the plate impedance of the 205-D is approximately 4,000 ohms (although every new tube you receive has a slip in the box carrying that information) but in any case you know that if the tube short-circuits, its resistance is destroyed. So you'll take the two rectifiers out of their sockets and test through them with a buzzer. The trouble may be located right there.

Running Down the Circuit

But suppose it is not. Suppose you have to look further. You know, of course, that the output of these rectifier tubes is filtered, and is then fed to the plates of the amplifier tubes. If you do not know this, the drawing will tell you. Let us go over this circuit, and notice the symbols as we go along.

We have already seen the transformer, T_5. It is drawn as two parallel coils, with some straight lines between them. But that is what a transformer is—two coils of wire wound on a core. The straight lines represent the core. It is not difficult to tell which coil is primary and which is

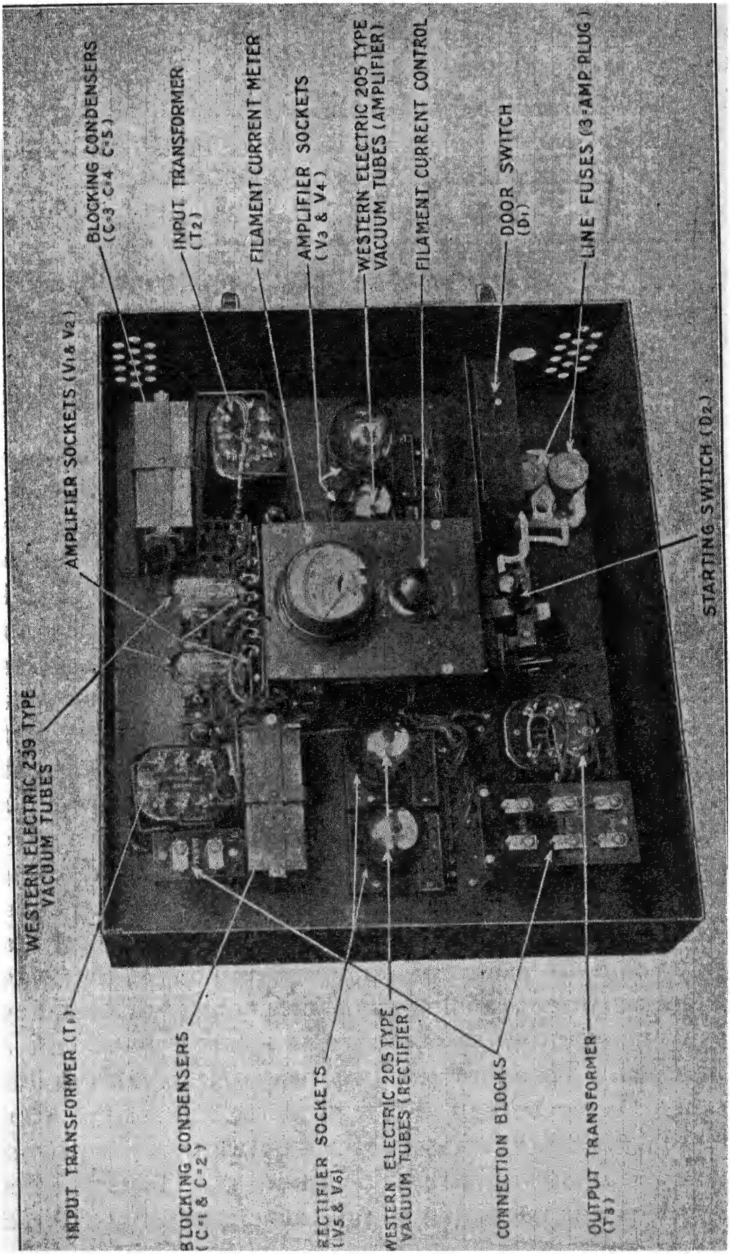

FIG. 52.—Internal view (front) of Western Electric 46A amplifier.

secondary. You will remember that this transformer is needed to step up the 110 volts of alternating current supplied, and will look to see which of the two coils is connected to the source of supply. The bottom coil on the drawing is the one, so the top coil is the secondary.

The terminals of the top coil are marked 3, 3T, and 4, both on the drawing and on the apparatus. Terminals 3 and 4 go to the plates of the two tubes. You will recognize the symbol for a tube, because it is composed of a V-shaped line for the filament, a little rectangle for the plate, and a zigzag line that can only be the grid.

The Full-wave Rectifier

These two tubes constitute a push-pull, or full-wave, rectifier; that is, one plate is always positive when the other is negative, and vice versa. So between them they handle both halves of the alternating current cycle, and the united output is much smoother than ordinary, or half-wave, rectification, in which only one tube is used and current flows across it only half of the time. Here current is always flowing, not through both tubes at once, but through either one or the other, depending on which plate is positive at any given moment. We know that this tube current consists of electrons given off by the heated filament, and attracted to a plate which is positively charged, that is, devoid of electrons. Looking at the drawing, we see that the electron current is fed into the secondary of transformer T_5 from both ends. It is also obvious that the circuit is not passed in at one end and out at the other, because no current can flow *out* of either end of this winding, that is, no electrons can flow across a tube *from* a plate *to* a filament. Therefore the only way out of this coil is through the center tap, 3T, and, in the line leading from this tap, current is always flowing outward, no matter at which end of the transformer it flows in. Thus the end product of this push-pull, or full-wave, rectifier is a direct current, fairly smooth, flowing in the wire leading from terminal 3T.

Following this line upward on the drawing, we come to a small dot that shows junction with another wire. Wherever two lines cross anywhere on this drawing, and a dot shows at the junction, a union between the two wires is indicated. Where no dot shows, the lines cross merely for the convenience of the draftsman, and there is no union

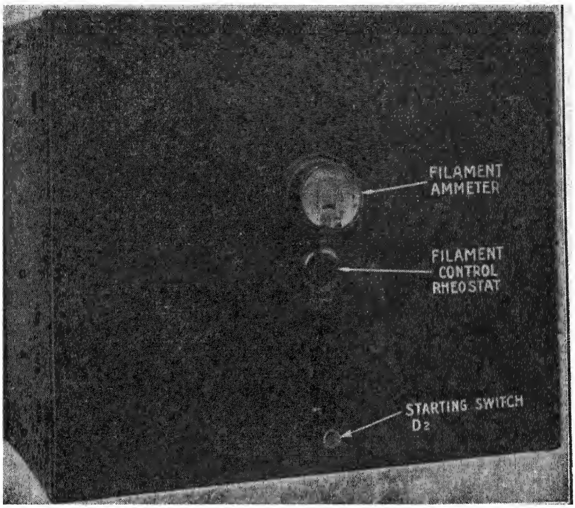

Fig. 53.—External view, front, of Western **Electric 46A amplifier. This amplifier is the same in fundamental design as the 46B shown in Fig. 54.**

between the wires which those lines represent.[1] Coming up this line, then, from terminal 3T on transformer T_5, our first junction shows us a line running to the left. Let us follow this line leftward to the next dot indicating a meeting of wires. From this dot we go upward a quarter of an inch to another, and then left again through a zigzag line marked R_{18} 575^{ω}. The little sign ω means ohms, and from this and the letter R we could guess, if we did not know, that such a zigzag line stands for a resistance. A zigzag line *always* means a resistance, *except* when it is

[1] Some types of drawings show a little jump in the line where it crosses another, to indicate that no meeting of wires is intended, and the black dots are not used.

associated with the other elements of a vacuum tube, and then it means a grid.

Coming out at the left of R_{18} we go downward, back to the right, and downward again to the center tap of one of the secondaries of transformer T_4. From this point we can take either of two courses out of that coil. It makes no difference which, since both lead to the filaments of tubes V_3 and V_4—the power amplifier tubes of this amplifier.

The Push-pull Amplifier

This stage of amplification reveals itself, by the center-tapped transformer windings around it (T_2 and T_3), to be a push-pull stage, that is, as one grid swings negative, the other swings positive. Both swing around the same central bias, which is supplied from the midpoint of the secondary of transformer T_2. Such an arrangement in a stage of power amplification gives something more than double power and improved quality as well.

Having followed our circuit to the filaments of this stage of power amplification, we know that from those filaments electrons are emitted which constitute a current across the tubes to the plates; the extent of current flow depending on the grid charge of the moment. Continuing now from the plates we find ourselves in the primary of transformer T_3.

The Chokes

But let us stop a moment to look at these transformers, T_2 and T_3, and while we are looking at them, we might glance all the way to the left and examine T_1. Here are parallel coils, but no straight lines indicating cores. Perhaps there are no cores. These may be air-core transformers, wound about a non-magnetic medium to give better quality with some loss of efficiency. Or perhaps the draftsman left out the sign of the core. That is sometimes done, and it is the case here.

We now come out at the midpoint of T_3 primary, and examine a new symbol, a coil of wire with some parallel

lines, which indicate that a core runs through it. Sometimes the same symbol is used with the lines drawn alongside the coil instead of through it. In either case the symbol means that there is a single winding on a core, and it represents, therefore, a choke coil—inductive winding,

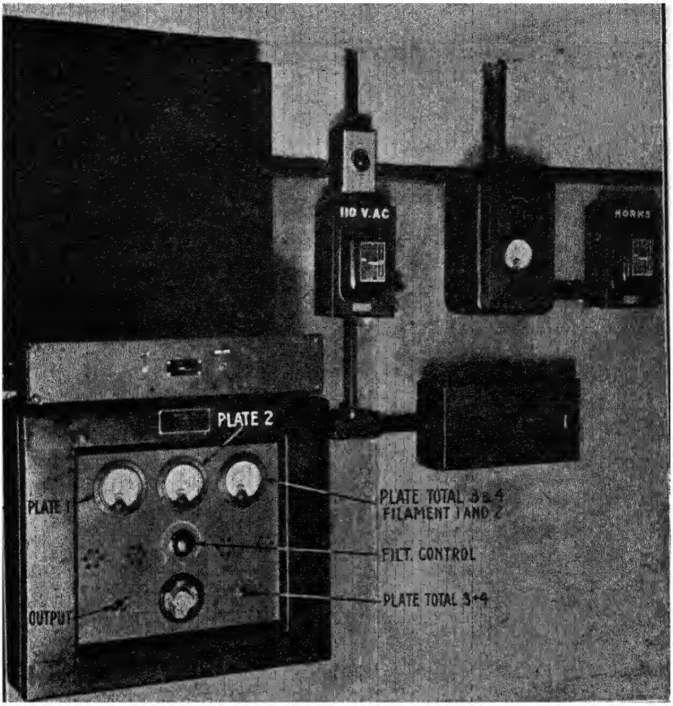

FIG. 54.—Front view of Western Electric 46B amplifier (the same in fundamental design as the 46A) shown installed below a synchronous-non-synchronous switching panel.

retard coil, reactance coil. Here these two chokes, L_1 and L_2 are called retard coils, 109*A* and 134*A*, respectively. Coming out at the lower end of L_2, we run down to the midpoint—point 5T—of another secondary of transformer T_4. This secondary feeds the filaments of tubes V_5 and V_6, and the filament emission from these tubes flows across to the plates, to the secondary of T_5. We have closed the circuit, and are back where we started. Anywhere along

the line we might have found the short circuit that was causing T_5 to become hot, and to smoke.

This trip around the circuit has taken some time, because we stopped to talk about a great many things we saw on the way. In actual practice, in running down trouble, it would take about 5 seconds. Now let us spend just about that much time to run back over it for indications of the short circuit that has burnt out our T_5 transformer.

Where Is the Short Circuit?

We have already checked tubes V_5 and V_6. The next in line is R_{18}, 575 ohms. This may be short-circuited internally. We could find out with a voltmeter, but let us go on to more probable causes, which will not take as much time. Next is the left-hand secondary of transformer T_4. This winding supplies the filaments of tubes V_3 and V_4, but if those tubes light normally, there is nothing the matter with that winding. Next we have those tubes themselves. A short-circuit in either would destroy the grid bias and, therefore, increase the plate current materially. Removing the tubes and testing across their contact studs with a voltmeter or headphones will reveal any internal short circuit that cannot be seen through the glass.

Next in order we have the primary of transformer T_3, the chokes L_1 and L_2, and the right-hand secondary of transformer T_4. This secondary may be absolved as long as the filaments of the rectifier tubes light normally.

The Condenser Block

But let us turn back to the choke coil, L_2. This is in a line of rectified current, and is therefore undoubtedly a part of a filter used to smooth out that current. But such filters usually include condensers, too. And the choke will be in series with the line, while the condensers will be across it. The drawing shows that this choke is in series. Now running right from its upper terminal we see a line broken by two short, parallel lines, marked $C_{6,7}$. Two parallel conductors spaced by white paper represent a

condenser. Directly below this condenser is another, marked $C_{8,9,10,11}$. Then here is the condenser block of our filter, apparently a good many condensers, but each group is shown as one condenser only, for the sake of simplicity in the drawing. And we see that they are across the line; for one side goes to the beginning of the circuit we traced, at the center point of T_5 secondary, and the other side of them goes to the end of the same line, the midpoint of the right-hand secondary of T_4. They are thus across the rectifier tubes, and across all the circuits those tubes supply.

Let us suppose (turning the power off) that we short-circuit the terminals of these condensers. We may then touch them with safety, and test through for a short circuit, using fairly high voltage to test with, so the short circuit will show. If one of these condensers *has* broken down, we do not need any further explanation of the trouble with transformer T_5.

Supposing this to be so, what can we do about it? Temporarily we can remove the condenser in question, dispensing with some of our filtering action while we restore a possibly noisy sound to the audience. We may not be able to do as much as that. If the condenser has been down long—before we saw and smelled smoke—we may need a new T_5 transformer before the amplifier will work for us again.

More Circuits

But suppose the trouble is not with the condensers; are there any more circuits to run down? Quite a few! Take the upper end of the choke, L_2. A branch circuit leads from this toward the left. Following the wire, we find the right-hand end of the resistor, R_{17}. From the other side of this resistor, one line goes up, through the 100,000 ohm resistance R_{10}, to supply the plate of tube V_2. Going back to the right-hand side of R_{17}, we see a line going down a bit,[1] then left, up again to R_{14}; through R_{14} and R_{13} and

[1] Through error the drawing omits a dot at this point to show that this line connects with the line to R_{17}.

up through R_2 to supply the plate of V_1. The return from these tubes is, of course, through the filament. It will be seen that these filaments are in series, that they connect to the line marked ($-$ 12 $v.$)—Gnd.—and that this line runs to the right, returning ultimately to the center tap of T_5 secondary.

The Wiring Diagram

We have taken a fairly long time now to trace lines on a drawing to find out why a transformer became hot, but

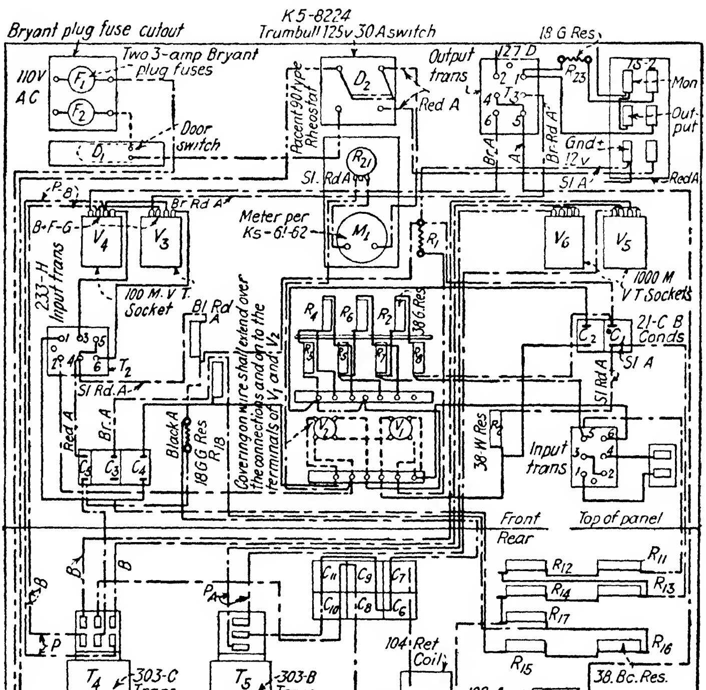

FIG. 55.—Wiring diagram of the Western Electric 46A amplifier, companion to the schematic diagram shown in Fig. 51.

think how much longer we would have taken if, instead of tracing a drawing, we had had to follow out wires in the amplifier itself. Is the drawing complicated? Rest for

a moment and think how the amplifier would look without any drawing. Opposite this page is the "wiring diagram" of the same amplifier. This shows how the interior actually looks. Here parts of the equipment are not arranged to

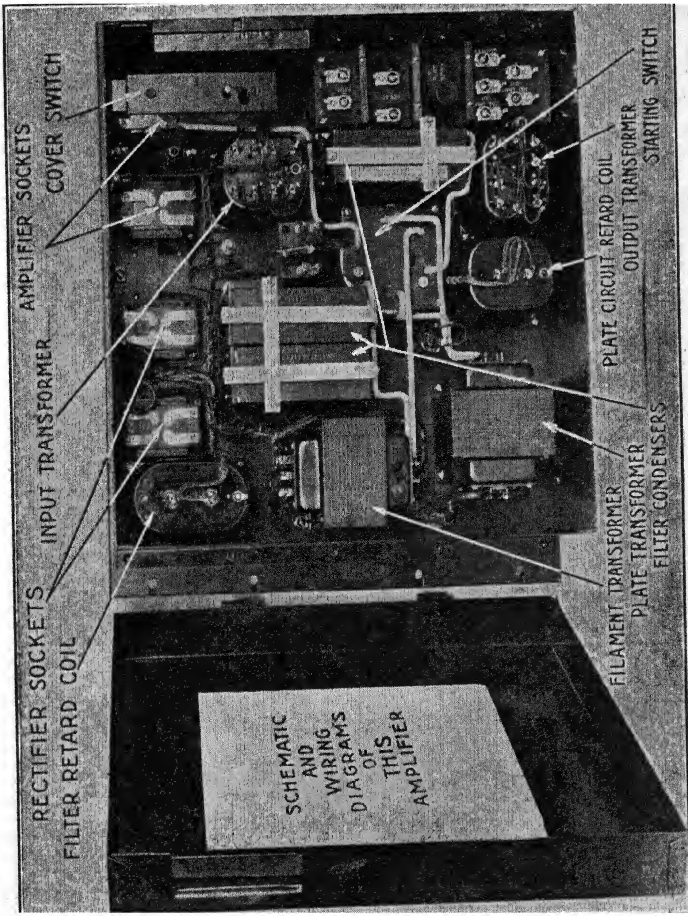

Fig. 56.—Internal rear view of Western Electric 42A amplifier, with built-in rectifier.

make it easier to see their electrical relations, but are placed exactly as they appear when one looks at the amplifier itself. Here the circuit is not made as short, and as easy to trace, as possible, but each connection is drawn exactly as it is wired in place. Even so, this drawing shows

more than the actual amplifier does. It reveals all the wires, including those which are hidden behind portions of the apparatus. The drawing helps to trace even those that are so tied up in a cable form that they cannot be traced in the amplifier itself. If you still think the schematic is complicated, turn back and look at it again.

FIG. 57.—External view of Western Electric 42A amplifier.

The function of the wiring diagram is to help you find, in the amplifier, wires and parts you have located on the schematic. It may be as easy to refer directly to the amplifier itself, but where a part or wire is hidden, the wiring drawing reveals it, in exactly the location it really occupies, and so saves time in finding it. When you have found just what you want in the schematic, you can turn to the wiring diagram, identify the same part there by its number, the same binding post by number, if you need to, and then identify that part or terminal in the amplifier itself, according to its physical position in the wiring drawing. This may seem complicated, but it is really an easy and rapid way of finding what you want.

Grid Bias

Let us return to our schematic. From the right-hand end of R_{18}, we see a line running upward, through the 100,000 ohm resistor, R_{20}, to the midpoint of T_2 secondary. Since this secondary supplies the grids of the two power amplifiers

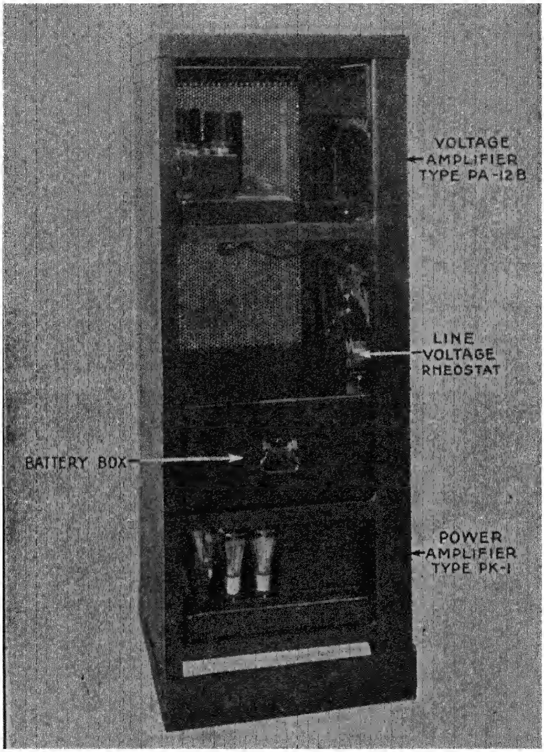

Fig. 58.—RCA-Photophone PA-21 amplifier assembly, used with type PG-10 equipment. The power amplifier at the bottom of this assembly is the same PK-1 shown in Figs. 60 and 61.

with speech voltage, the line now under investigation must be to provide the grid bias. This bias is intended to keep the grid negative with respect to the filament. If we investigate we find that there is current flowing across the 575-ohm resistor, R_{18}, and the left-hand end of it, as shown on the drawing, is the positive end. You can trace this for

yourself, if you like, starting at the ground terminal (-12 *v.*) in the lower left of the drawing, and running the circuit back to the right-hand side of R_{18}. Going back still further toward the positive end, we go through R_{18}, and back through the transformer to the filaments of V_3 and V_4. Therefore the grids, which connect to the right-hand terminal of R_{18}, are negative with respect to the filaments, which connect with the left end of R_{18}, the extent of the bias being equal to the voltage used up by this resistor.[1]

As for V_1 and V_2, their filaments are not supplied from a transformer, but with 12 volts of direct current from a battery or a direct current generator, depending on the system.[2] Their grids are biased simply by being connected to the negative side of this line. This leaves them negative with respect to their filaments, which are on the positive side of the same line, connecting to negative across the resistor R_1. The voltage drop across R_1 gives the bias of V_1, while the drop across R_1 *plus* the drop in the filament of V_1 gives the bias of V_2.

Most sound amplifiers are provided with grid bias somewhat in the manner we have just stated; a few use C batteries in series with the grid.

The Speech Circuit

The speech circuit enters this amplifier at the primary of the input transformer, T_1. The current pulsations in this primary set up voltage pulsations in the secondary. No appreciable current flows in the secondary because the circuit is not closed, it is open at the grid of V_1. But fluctuations in the voltage of the grid of V_1 result, and these fluctuations vary the number of electrons, emitted from the filament, that reach the plate of V_1, and modulate the

[1] Voltage, or electrical pressure (potential), is lost in forcing current through a resistance. The extent of this loss, or "drop," depends on the amount of current the potential has to push and on the size of the resistance through which the pushing is done. The drop, in volts, equals the current in amperes multiplied by the resistance in ohms.

[2] Rectifiers have recently come into use for this purpose.

plate current, accordingly. The V_1 plate current fluctuations will therefore, be stronger than those which flowed in T_1 primary. Hence, the speech currents originally fed into this amplifier have been increased.

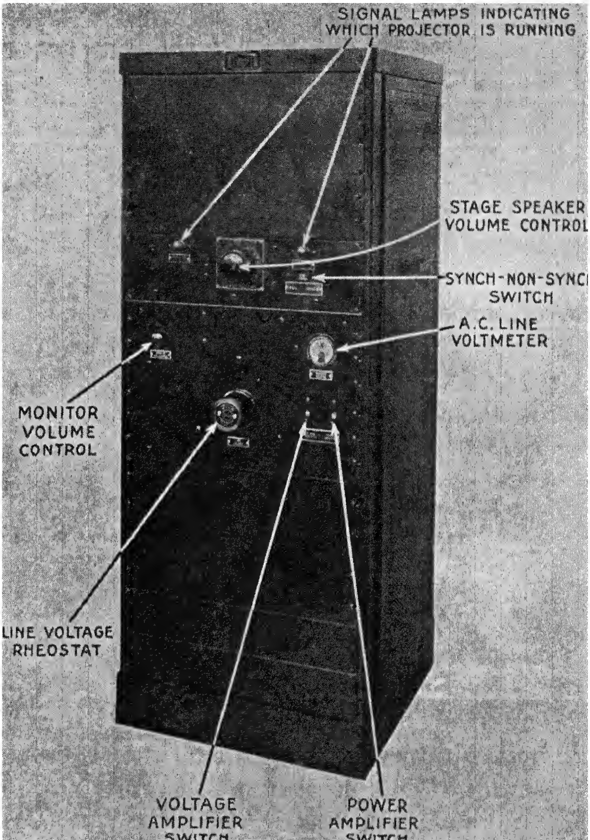

Fig. 59.—Front view of the RCA-Photophone amplifier rack shown in Fig. 58.

Further increase is necessary, and the next stage of it takes place in V_2. The condenser C_2, at the top of the drawing, between these two tubes, is connected with one plate leading to the positive B voltage of V_1, and the other plate to the negative bias of the grid of V_2 through the

tapped resistance, $R_3 \ldots R_9$. With each fluctuation of voltage in the plate circuit of V_1, there will be a change in the charge on the positive side of this condenser. In the nature of condenser action a corresponding change in the negative charge, on the other side, follows automatically, resulting in fluctuation of the charge on the grid of V_2.

In this case, not all of the voltage fluctuation of the condenser will reach the grid. A certain portion is by-passed through the tapped resistor, $R_3 \ldots R_9$. The exact amount that is by-passed will depend on where the soldered connection is placed. This resistor, then, acts as a volume control for the amplifier.

In the plate circuit of V_2, the alternate charge and discharge of condenser C_4, following the amplified speech fluctuations in V_2 plate current, create a pulsating current through the primary of T_2. A corresponding alternating current is induced in the secondary of this transformer, with the result that the grids of V_3 and V_4 swing in opposite directions, causing an alternating plate current to flow in the secondary of T_3. This current is then fed into units of the loud speaker.

Odds and Ends

One symbol has been overlooked in going over this schematic. Near the bottom of the drawing, in series with the milliammeter M_1, will be seen a resistance, partly shorted by an arrowhead contact. The arrow means *variable* contact. This particular resistance is obviously a rheostat, controlling the filament supply to the first two tubes. In any of these drawings, an arrow, except where obviously used to connect some printed remark with a particular portion of the circuit, means that the contact indicated by the arrow is variable, or that the resistance, coil, condenser, or other apparatus, crossed by an arrow, can be varied in value.

Just to the right of the 110-volt alternating current input on this drawing is a switch marked D_1. This is the

"door switch"—a contact so arranged that the power is cut off when the amplifier is opened. It is a safety device, and many power amplifiers have it. If your amplifier does not work after you have had it open, make sure that this switch has been pressed all of the way down; sometimes they fail to close.

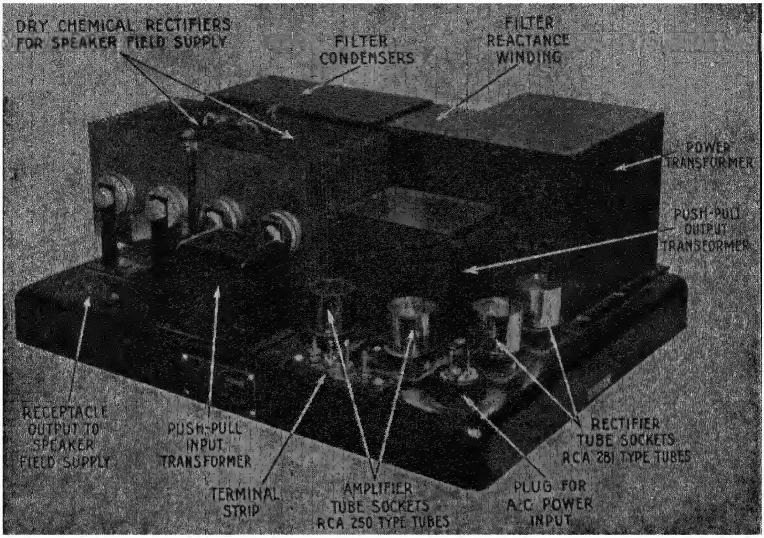

FIG. 60.—RCA-Photophone type PK-1 power amplifier, embodying one stage of push-pull amplification and a "dry chemical" rectifier for loud-speaker field supply.

SYMBOLS AND CIRCUITS

We have gone over many symbols, and in doing so, we have traced out a complete amplifier circuit. This particular drawing, as was said at the beginning of the chapter, contains practically all of the symbols in common use. But that is not the only reason it was chosen as a sample drawing. The amplifier it represents is probably the most widely used of any sound amplifier. There are several of this type, but the others differ from this one only in having a few more meters, and a switch that connects one of the meters into either of two different circuits. The drawing

here reproduced avoids that complication and was therefore selected to illustrate all amplifiers of this type.

But there is still another reason why this particular amplifier was chosen as our example. It embodies within itself nearly all the amplifier circuits there are. It has transformer and capacitative coupling between tubes, two different methods of furnishing grid bias, and it incorporates within itself a complete rectifier from which B voltages, as needed by the different tubes, are secured by means of

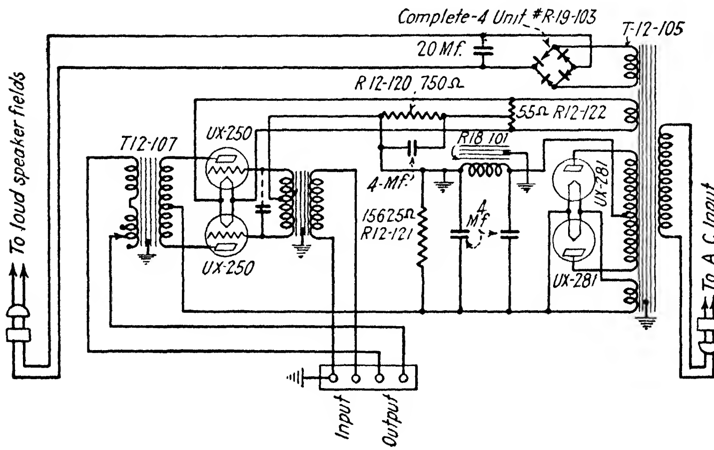

FIG. 61.—Schematic diagram of the RCA-Photophone PK-1 amplifier, pictured in Fig. 60. The complete 4-unit R-19-103 shown at the top right is a copper oxide "dry chemical" rectifier.

tapping a series of resistances between the output of the rectifier and ground.

You are unlikely to have in your projection room an amplifier that uses any apparatus or principle not covered in this chapter. The exact construction of some part, or the exact application of some principle, may differ, but if you keep in mind what a tube does, what a transformer does, what a condenser does, what voltage drop across a resistance does, what a choke does, you are not likely to find any difficulty which is beyond your analysis. But this subject will come up again, in the chapter dealing with methods of finding trouble.

It would be interesting to trace here the circuits of the 20 or 30 sound amplifiers in most common use, but it would not be practical. A very popular amplifier has been chosen, and it is luckily one that includes in some form substantially everything that is likely to be found in any other. The reader may find it interesting to open up his own amplifiers and study the drawings that are probably pasted inside. When a day of trouble comes he will certainly find it profitable to have done so.

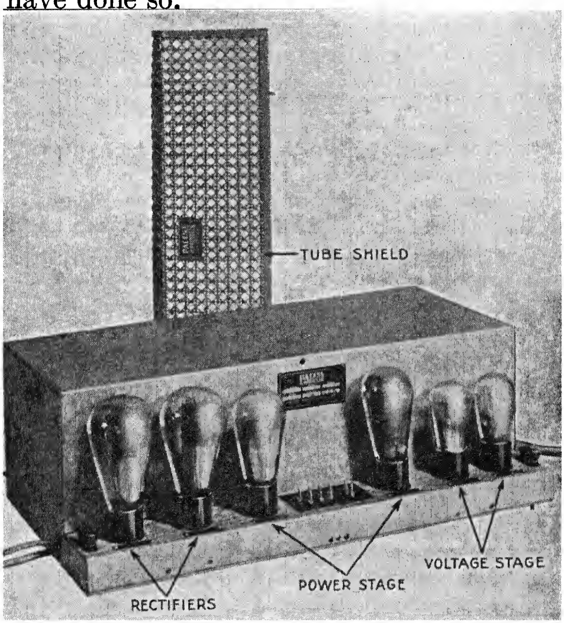

FIG. 62.—Pacent standard medium-power theatre amplifier, showing protecting tube shield removed from its place in front of the tubes.

In the past some manufacturers have not thought it good policy to furnish drawings with their equipment, but today a little diplomacy will nearly always procure them. What is most needed is to convince the company in question that the drawings are wanted for legitimate use in emergency, and not to help in unauthorized experiments with the apparatus on which they are staking their reputation.

Just a Step Aside

The next matter for consideration will be acoustics, and then we shall deal with loud speakers. The reason for this departure from a strictly logical order will become plain when we go into the question of matching impedances, which is sometimes very important in speaker circuits. You will find it very easy to understand the necessity for impedance match when the facts of the case can be illustrated by examples of similar action in acoustics and in optics.

Ten Questions

1. What is the purpose of a schematic drawing?
2. What is the purpose of a wiring diagram?
3. How do these drawings help in running down amplifier trouble?
4. If an amplifier has several tubes, needing several different plate voltages, how can these be obtained from one rectifier?
5. How can a C, or grid bias, be obtained without using C batteries?
6. If you see a choke coil in the output of a rectifier, what other piece of apparatus would you look for in the same circuit?
7. If the filter condensers of a rectifier short-circuited, what result might be expected?
8. Name two devices that may be used to couple the plate circuit of one tube to the grid circuit of the next.
9. In the amplifier just gone over, how were the filaments lit?
10. Draw as many of the electrical symbols as you can remember.

Ten Answers

1. To show the electrical relationships of parts of a circuit as simply as possible; by using symbols for each piece of equipment and so arranging these that the connecting wires may often be drawn as straight lines.
2. To help locate in the actual equipment parts that may be unmarked, or may be hidden behind other parts; often, also, to indicate by numbered terminals where each wire in the apparatus begins and ends, and where it joins other wires, thus saving tearing apart cable forms, tedious buzzing, or removing some piece of equipment unnecessarily to look at the wires behind it.
3. The schematic makes it possible to trace (on paper) the circuit in which the trouble appears, and by its comparative clarity prevents confusion with other circuits. The wiring diagram helps locate in the apparatus the wire or part suspected, from study of the schematic, of causing the trouble.
4. By connecting the rectifier output to ground through a series of resistances. By tapping into the resistance line any desired voltage above ground can be obtained.

5. By inserting a resistance in series with either a filament or a plate circuit, and using the voltage drop across it. The filament is then connected to the positive side of such a resistance, and the grid to the negative side. For a very small bias the grid may simply be connected to the negative side of the filament. Since the filament is itself a resistance, it will have a somewhat higher potential, as a whole, than its negative terminal.

6. Condensers, as part of the filter.

7. Since they are connected across the line, they would constitute a short-circuit on the rectifier, overloading it, and burning out its transformer. Perhaps the tubes would "flash over"—arc across between plate and filament.

8. A transformer. A condenser.

9. V_1 and V_2 are in series and supplied from an external source of 12 volts, direct current; V_3 and V_4 are supplied from one secondary of a transformer; and V_5 and V_6 from another secondary of the same. These last four filaments are therefore lit by alternating current.

10. See back of book.

CHAPTER IX

ACOUSTICS

It may be fair to assume that acoustic troubles are the major sound troubles in theatre work today.

The pick-up action, whether film or disc, the switches and volume controls, the amplifiers with their complicated circuits and the loud speakers, all together, probably cause less bad sound than the action of the sound waves themselves after they have been set free in the house.

Sound waves travel at (roughly) about 1,000 feet per second. The lowest frequency an average human ear can appreciate is about 16 cycles per second. The space between the crests of waves at this frequency—the distances at which they follow each other—will be about 62 feet. Some ears can hear as high as 16,000 cycles, or waves whose crests are only 1/16 foot apart.[1] The practical reproduction of sound for theatre work involves only from 60 to about 6,000 cycles, and very few systems are good enough to handle that range with perfect fidelity.

The alternate areas of condensation and rarefaction of air, spreading in all directions from the loud speaker, come in contact with the walls and ceiling and floor; with the bodies of the audience and with any other objects in the auditorium. If some objects—such as glass pendants of an electrolier—have a natural vibratory rate within the sound range, the sound waves will set them to vibrating. These objects will then generate new sound waves of their own, which will reïnforce the sound at that one frequency. They will continue vibrating, perhaps, after the original sound has died out. The condition is happily rare, but extremely troublesome when it does exist.

[1] Naturally, the spacing between the waves will depend on how quickly they follow each other—that is, on the frequency.

Reverberation

Every object in the auditorium will reflect some portion of the waves of condensation and rarefaction reaching it. Generally speaking, the harder such an object is, the more sound it will reflect. A concrete floor reflects very much more sound than a heavy carpet. But the carpet will also reflect some.

Since sound travels at 1,000 feet per second, and theatres do not generally measure 1,000 feet in any dimension, sound in the average theatre may bounce back and forth between walls like a tennis ball, over a period of a second or more. With each reflection the wave loses some of its energy, until it dies out altogether.

This "tennis ball" characteristic of sound in a closed space is called reverberation. In special cases a curvature of some of the enclosing surfaces, or some other peculiarity, concentrates a great deal of reflected sound in one area. The result is a distinct echo. An echo may be regarded as any reflected sound reaching the listener a second or so after the original sound has passed. Concentrated reflection may create an aggravated echo condition.

Now the object of sound reproduction in theatres is to duplicate natural sounds as nearly as possible. Only a bird or a parachute jumper has ever heard sound with no reverberation at all. It is possible to prevent reverberation almost completely by enclosing a room with sound absorbing material, but this radical cure is worse than the disease. No word or instrument seems natural in such a room because we do not hear voices or music ordinarily under such conditions. For good reproduction a theatre needs some reverberation, but not too much. The ideal condition is that which reproduces the normal circumstances under which we hear sounds.

Any theatre has an ideal "time of reverberation," depending on its size.[1] "Acceptable" times vary from

[1] If you care to, you can check the reverberation time of your own house, under audience conditions, by listening for a gunshot or some other short,

less than 1 second in the smaller houses to as much as 3 seconds in the largest. But timing reverberation is seldom necessary. The character of normal reproduction in most theatres will indicate readily enough whether there is too much reverberation.[1] If this is the case, sound will be hard—clanging. It will be more so in wide, open places like the balcony than in rather sheltered ones like the orchestra under the balcony, because in those places where floor and ceiling are close together, the sound bounces many more times per second, and so dies out more quickly.

Treatment for reverberation consists of covering exposed surfaces of the theatre with sound-absorbing material. The extent of the surface to be covered depends on how much more absorption is needed to secure a suitable reverberation time and how efficient the chosen material is in absorbing. It will also depend somewhat on where this material is placed; if distribution is uneven, more sound will be absorbed by the same material when it is placed where sound is loudest.

An audience absorbs sound very well, and estimates for acoustic draping are based on an average audience condition. Nearly perfect results can be had with all audiences only if the seats are heavily upholstered, so that they have about the same "coefficient of absorption," whether occupied or not. But proper treatment of walls and

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sharp sound, followed instantly by silence, and timing to see how long the sound takes to decrease to a level where it can no longer be heard. With no audience present, the commonest practice is to time the reverberation of a hand clap.

[1] In treating a house for reverberation, acoustic engineers calculate the time, as a more accurate method than observation with a stopwatch. These calculations involve the cubical contents of the theatre, the reflecting surfaces present and the "coefficient of absorption" of each different surface—that is, the degree to which the material in question absorbs sound. These coefficients have been found for all the commoner building materials, and are listed in the standard textbooks of acoustics. If you wish to make calculations upon your own theatre, you can get all the information needed for fair results from the Bureau of Standards, Washington, D. C. but you will be well advised to leave the necessary calculations in the hands of experts. Mistakes made in acoustic treatment are sometimes very expensive.

ceiling will give reasonably satisfactory results with all audiences and any type of seats.

Echoes

Since echoes are special cases of reflected sound, their cure in most cases involves locating the surfaces that are causing the reflection, and then covering them with sound-absorbing materials. Generally these surfaces will be curved, but this is not always the case, sometimes peculiar arrangements of flat walls will have the same effect. The cause of echoes may often be determined by walking about the theatre and listening for reflected sound.[1] But in other cases the echo will be thrown back and downward through the upper air of the theatre where no one can walk; in such circumstances finding the source may be difficult.

One ingenious device for locating causes of echo is a parabolic mirror—the same kind that is used in a search-light—with a receiver unit mounted to face the mirror. Such a contrivance throws a beam of sound, allowing very little to spread about. It is pointed with the help of an ordinary hand flashlight, which is mounted to act like the sights of a gun. When the theatre is darkened this apparatus is twisted about. The sound beam is thrown against different surfaces. The light shows where the sound strikes. Whenever echo is heard, the surface illuminated at that moment is the source of it.

A more difficult way than this, but one requiring no special apparatus, is to drape suspected points successively with some heavy, sound-absorbing substance—such as thick velour or ozite, a material which is often used under carpets—and to note the effect upon the echo with each change in the location of the drape.

The very easiest way is to note probable reflecting angles on a set of architects' plans.

[1] In addition, the angle of reflection must be taken into consideration. It will always be equal to the angle at which the original sound strikes the reflecting surface. If you will think of the original sound as a beam of light and the reflecting wall or ceiling as a mirror this will be plain enough.

Echoes limited to very small areas will nearly always be found to be due to some small curvature of wall or ceiling in the immediate vicinity and are most easily cured by draping that point.

A special case of echo is sometimes found, when the theatre is so shaped that the top of the balcony is very close to the ceiling. In rare instances construction of this kind has been known to make the whole theatre act like a giant megaphone. The upper balcony is very "dead," has no reverberation at all, because very little of the sound reaching its walls and roof gets to the ears of the audience in that area—all of it is thrown down and forward to create an echo in the front orchestra. Extensive draping of the balcony area cures the echo, but does not give the balcony any more reverberation, therefore draping, wherever possible, should be replaced by "coffering."

Coffering is breaking up the reflecting surfaces into recesses about 3 or 4 feet square, and fairly deep. Such recesses reflect sound, but break up waves of the more important frequencies, and so change echo into reverberation by dispersing the reflected sounds in all directions.

Echo can very often be cured, when the speakers are "directional," by pointing them away from the surface that is causing the trouble. In other cases this cannot be done without making sound in that portion of the theatre materially weaker than elsewhere, and draping or coffering must be resorted to.

Acoustic Distortion

No material reflects all frequencies alike. In general, the higher frequencies are reflected least. On the other hand, higher frequencies travel more nearly in straight lines; they do not lose themselves so easily by bending around obstructions, and hence are more likely to be reflected than the lower tones. Out of these conflicting conditions a situation may arise where some part of the theatre has a dead spot or a loud spot, over certain bands of

frequencies only, resulting in distortion of sound. This distortion may go so far as to make speech seriously indistinct.

Standing Waves

A few paragraphs back, there was mention of the rather rare, but by no means unknown, condition where some object, capable of vibrating at sound frequencies, goes into induced vibration at its own natural period, and thus reïnforces certain tones and sets up distortion.

It may happen that two opposing and reflecting surfaces of the theatre are so located as to constitute what might be called a "tuned channel," for some particular frequency. The section of air between these opposing and reflecting surfaces may be of exactly such length that at certain frequencies no wave of condensation, reflected, meets and is lost in a wave of rarefaction; but rather, meets and reïnforces, every time, another wave of condensation. The result is that sound within one band of frequencies takes a very long time to die out between these two surfaces. What is known as a "standing wave" is set up in this area. This naturally can create very considerable distortion which often results in making speech practically unintelligible. Locating and draping the guilty surfaces is, of course, one cure; repointing the horns, when considerations of distribution allow, may be an easier remedy.

Complicated Acoustic Problems

It can be seen that acoustic questions are not always simple. But two prime considerations complicate every acoustic problem thus far considered. One is that draping is never merely a matter of hanging velour where it is wanted. The decorative scheme of the theatre has to be considered, and so does the expense. In addition many local authorities are now adding a further, though minor, difficulty by insisting that all sound-absorbing material used must be fireproof.

The second complication is that above all these other considerations is always the primary one of distribution—

the volume must be even in every part of the theatre if all patrons are to hear with comfort.

DISTRIBUTION

A horn nearly always has a "beam." It "shoots" sound in somewhat the manner that a gun does—or as a garden hose sends out a concentrated stream of water, surrounded on every side by a fine spray. The stream, at its far end, also spreads into a spray.

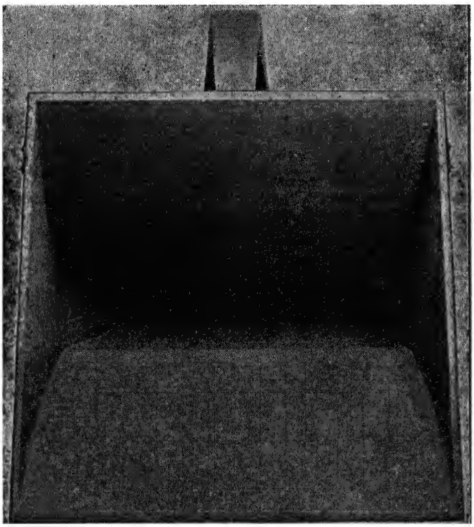


FIG. 63.—Western Electric type 12A horn, front view.

Distribution with such horns involves keeping the stream in the air over the heads of patrons, and spreading the spray evenly to every seat.

Absolutely perfect distribution does not exist, and the larger the house, the smaller the chance of approaching perfection. It is impossible to avoid the direct "beam effect" altogether; the beam is never sharp enough for that. Beams can be distinguished easily by walking across a theatre—in them sound is more "brilliant,"

more clearly defined. The reason is that the higher frequencies, which travel in straight lines with little tendency to spray out in graceful curves, are naturally stronger in the beam than elsewhere. Fortunately, audiences do not walk about with critical ears, and therefore acceptable adjustments can nearly always be made.

Some horns, especially those built very flat to save room behind the screen, have an extremely broad beam, in fact, almost none. Sound of all frequencies is thrown out from them in every direction. These give excellent results in many houses, but sometimes cause difficulties in the larger ones, where it is harder to "aim" sound at the exact points desired. Cone speakers, unhelped by "directional baffles," have practically no beam either, and should not be used in theatres large enough to make exact placing of sound important.

Securing satisfactory distribution is generally not difficult, if a sufficient number of speakers is used, except where one or more of the special acoustic problems, already described, intrude and require unusual pointing of the horns.

A sufficiently accurate test for distribution, in most cases, is to walk about the house with no audience present—so areas between aisles can be properly covered—listening not only for equal volume but for equal clarity. If clarity is not substantially the same everywhere that may mean that there is acoustic trouble, but it may also mean merely that the horns are not properly placed. The higher frequencies should have particular attention in this check; low tones will tend to spread out and equalize themselves; it is the highs, traveling in straight lines, that give clarity and brilliant definition, and that will not be evenly distributed unless the horns are placed just as they should be. Securing good distribution in most houses is a task which takes hours, and miles of walking, and infinite patience. With enough patience many minor acoustic problems can be cured by proper placing of the horns. But excessively minute attention to distribution with cones (except where

they have directional baffles) or with horns that do not have fairly sharp beams, is pure waste of money and time.

One test that often helps in distribution is to secure a constant frequency reel of 1,000 cycles. Run this so low that bringing the volume down one more step makes it totally inaudible. Then walk around the house, noting those places where the sound disappears. If a point can be found where the sound seems a little too loud, bring the volume down one step and see if it is still audible—if so, that is a loud spot. Repeat this test, repointing the horns as indicated, until excellent distribution on 1,000 cycles is obtained. The beauty of this method is its precision; but it is only a help; and is not always final. The addition of other frequencies and of full volume may still allow serious discrepancies or distortions to creep in. These can be checked, after distribution at 1,000 cycles has been found, or made, satisfactory by playing ordinary speech at normal level.

A record cannot be used in place of the reel for this constant frequency test. Anywhere near the projection room the faint tone set up by the needle in the air around it may be audible although no sound at all is coming from the horns. Then anyone will naturally think sound in the top balcony is satisfactory whether it really is or not.

Boxing the Horns

Generally, the speakers should be surrounded by a box of soundproof material, such as heavy velour with a substantial "gather," ozite, elrap, or some similar substance. Canvas and cheese cloth are of no use whatever. The box should leave no easy exit for the sound except forward through the screen. Acoustic troubles may or may not exist in the auditorium, but in either case there is no reason for inviting further complications from the hard floor and bare walls behind the speakers. The box, if properly made of the right material, insures that no sound that gets back of it will be strong enough to do any harm.

False Echo

An apparent echo in the front of the auditorium may be due to the beam passing by overhead, in which case sound in that area will be sufficiently weak for normal reverberation from the rear to create the impression of an echo. The remedy is to depress the beam, installing additional horns if necessary.

Hard Walls Not Always Reverberant

Occasionally a small theatre may contain few sound-absorbing surfaces, or none at all, and still not be unpleasantly reverberant. The hard walls will be so placed, and sufficiently close to each other, to reflect sound back and forth a great many times per second, depriving the waves of their energy before they become objectionally prolonged.

Ten Questions

1. What happens to a sound wave that meets a hard surface?
2. What can be wrong with a theatre when all the sound waves meet hard surfaces?
3. Under what conditions can a pair of hard surfaces, opposite each other, give rise to "standing waves"?
4. How can you cure the result of too much hard surface in your theatre?
5. What can be done about a reflecting surface causing echo, other than draping it with sound-absorbing material?
6. What is the relation between the angle at which sound waves meet any surface and the angle at which they are reflected from that surface?
7. What, beside wrong pointing of horns, can give rise to a loud spot?
8. What would be the effect of no hard surface whatever in your theatre (100 per cent sound absorption)?
9. What is "an acceptable time of reverberation"?
10. Why is it necessary to raise the volume with a full audience? Why are reverberation troubles often lessened when the theatre is full?

Ten Answers

1. It is reflected, with some loss of its energy.
2. Too much reverberation—but the size of the house is an important factor in this.
3. When an area of condensation or rarefaction is reflected back and forth between these surfaces in such time that it always meets and reïnforces another area of condensation or rarefaction. Such a "tuned channel" for any given band of frequencies can set up "standing waves" within that band.

4. By draping or plastering some of it with sound-absorbing material.

5. The surface may be coffered, or broken up, which will convert the echo into reverberation.

6. The angle of incidence is equal to the angle of reflection.

7. Reflected sound concentrated in one area, arriving too soon after the original sound to be regarded as echo.

8. Sound without any life or sparkle—very unnatural and rather unpleasant.

9. The time a short, sharp sound, followed by silence, takes to decrease below limits of audibility is the time of reverberation. The acceptable time is that which gives natural and pleasing sound, and varies from less than 1 to more than 3 seconds—the larger auditorium having the longer time. The natural and pleasing character of sound in the different parts of a theatre is sufficiently accurate guide to reverberation conditions.

10. Because the bodies and clothing of the audience are very efficient at absorbing sound.

CHAPTER X

THE LOUD SPEAKER

Compared with the other apparatus which we have been looking over, the action of the loud-speaker "unit," or receiver, presents no particular difficulties.

Let us consider first the ordinary telephone receiver. This contains a disc of thin iron, which is capable of being attracted by a magnet. A magnet is present. The disc is so mounted that it can not be pulled into actual contact with the magnet; its center merely leans inward a little in answer to the attraction. There is a certain amount of spring in the disc; if the magnet's pull were destroyed the center would snap back.

But there are two magnets in the telephone receiver. The second is an electro-magnet, which consists of a coil of wire wound about soft iron, or a suitable alloy. When current is fed through this electro-magnet, it either reïnforces or opposes the steady field, depending on the polarity of the current. In consequence, the joint magnetic pull on the metal disc changes—and the disc either bends inward further, or draws away a little, according to the current's polarity.

The extent to which the center of the disc will move will depend upon the strength of the variations of the current, which govern the strength of the electro-magnet. If the current is pulsating at speech frequencies, the position of the disc will alter at speech frequencies. The beating of the disc against the air around it sets up corresponding waves of condensation and rarefaction which our ears perceive as sound.

Receivers based on this principle were used in the earlier radio loud speakers, the air waves set up by the motion of the disc being concentrated and somewhat modified by a horn.

THE DYNAMIC SPEAKER

In the instrument just described the disc, or diaphragm, is the only moving part.

The "dynamic" speaker secures greater power by providing a stronger steady magnetic field; it uses an electro-magnet. This winding is commonly known as the "field coil." The coil carrying the speech currents is mounted so as to be free to move, and the diaphragm that beats against air is mounted on the speech coil and moves with it.

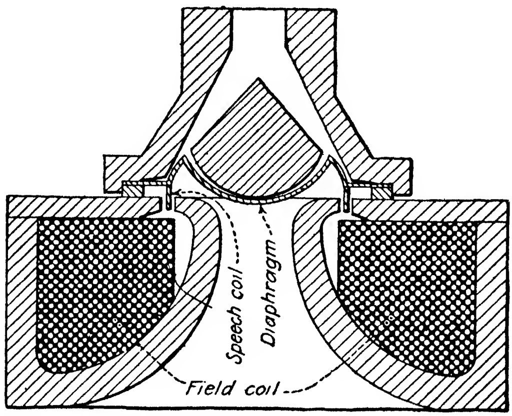


FIG. 64.—Drawing showing sectional view of Western Electric 555W receiver.

We have already seen that a light magnet free to move, such as a compass needle, is attracted by a wire carrying current. If the magnet were fastened down and the wire free to move, the same attraction would pull the wire toward the magnet. The reaction between the steady electro-magnet of the dynamic speaker and the current carried in the speech coil results, because of the structure of the device, in the vibrations of that coil.

The frequency with which the speech winding plunges forward and back will naturally follow the frequency of the changes in the strength of the speech current. The extent, or amplitude, of these current changes will govern the distance through which the coil moves. Now since the time allowed this coil to complete one cycle of motion

forward and back depends solely on the frequency of the imposed current, it follows that with greater strength of current the coil must move more strongly—to cover a greater distance in the given time. Hence the diaphragm attached to it moves more strongly and beats the surrounding air more strongly, thereby producing greater compression and greater rarefaction, and therefore louder sound.

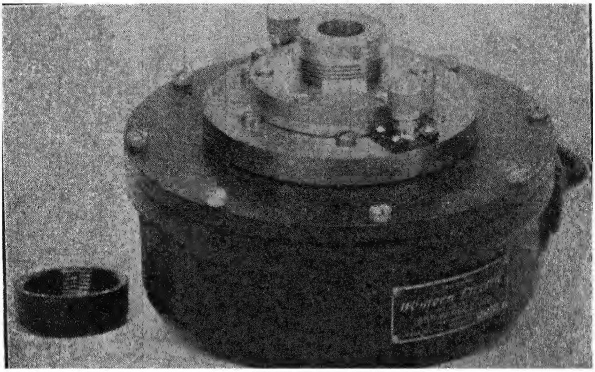


FIG. 65.—Western Electric 555W receiver, used with the type 12A horn shown in Fig. 63, and with other Western Electric horns.

It will be remembered that the loudness of a sound depends on the degree of compression and the corresponding degree of rarefaction.

The action of the receiver is thus exactly the reverse of that of the disc reproducer. In the one case, physical motion in a magnetic field generates electric current; in the other, current flowing in a conductor, lying within a magnetic field, generates physical motion. These are merely two opposite sides of the same fundamental relationship.

Sources of Field Current

The current for the "field winding" is sometimes supplied from storage batteries. Sometimes it is secured by stepping down alternating current, and then rectifying and filtering it. The field coil, being itself a rather large

inductive winding, is usually capable of handling the filtering without any further help.

Vacuum tubes are often used for the rectification; a complete field circuit of this type may consist of a cord going to the alternating current supply, a stepdown transformer, and a rectifier tube. Occasionally the tube is replaced by a "dry" rectifier[1]—a device which takes advantage of the property that certain chemical arrangements have of passing current in one direction only.

Again, the receiver field may be supplied by a motor-generator. Still another method, now coming into somewhat restricted use, takes the field current from the direct-current generator which is used to supply the projection arcs, and reduces the voltage, as needed, with a rheostat.

Horn and Cone Speakers

Where the receiver is meant to work through a horn, the diaphragm attached to the speech coil will be quite small, but will move through comparatively large distances. In the cone speaker, a large diaphragm mounted to the coil by any of several methods moves through comparatively small distances.

A horn-type "unit" should never be played apart from its horn. Without an air column to push against, the device will ruin itself. Either the speech coil will tear

[1] To form this rectifier, small discs of copper are heated until the surface corrodes into cuprous oxide. The film of corrosion is then cleaned from one surface; the other is left untouched. For reasons still unknown, this arrangement will conduct current in one direction only.

In the commercial form a number of such discs are used in series. Washers of lead or other soft metal are placed between the discs to secure better contact (they have no part in the rectifying action). Contact is further secured by running an insulated bolt through the length of the assembly, and making up tight on the holding nut. Poor contact and the consequent drop in the current passing, due to this nut becoming slightly loose, is almost the only trouble a well-made device of this sort will give.

The rectifier generates some heat, and to radiate this away, copper flanges often are arranged to extend some distance from it into the surrounding air.

loose from the diaphragm, or the fine wires connecting to that coil will break, as the result of excessive motion. The same, of course, follows even when the speaker is properly mounted to a horn, if too much volume is forced from it.

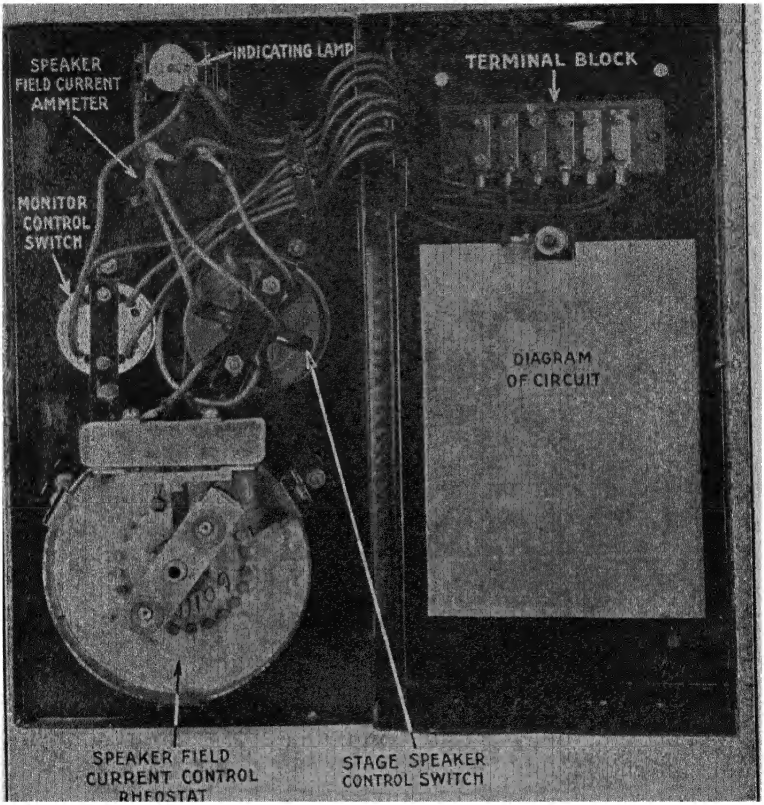


FIG. 66.—Internal view of Western Electric KS 6540 receiver-field control cabinet for supplying direct current from generator to a number of 555W receiver field windings.

The diaphragm of the cone speaker may be made of paper, specially treated linen, or any of a number of substances now available. The larger area of such a diaphragm will set a greater amount of air in motion, and so render the megaphone action of the horn unnecessary;

the wider surface of air it has to push against will "load" it sufficiently without an air column.

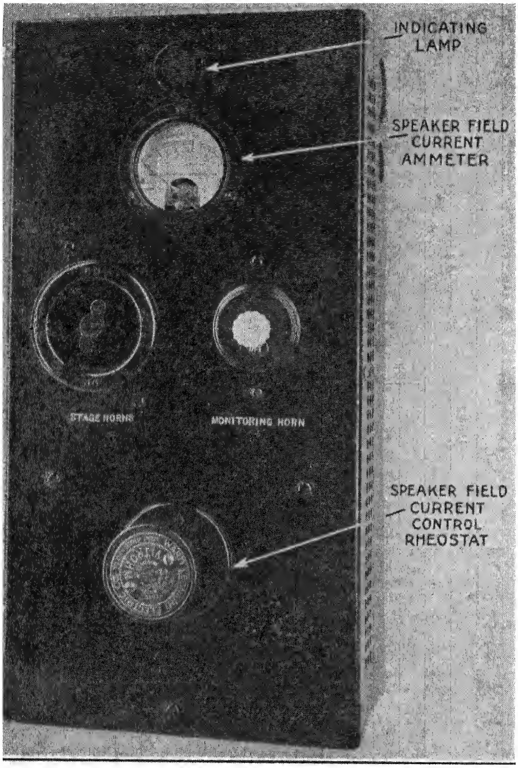


FIG. 67.—External view of the Western Electric KS 6540 receiver-field control cabinet, shown in Fig. 66.

BAFFLES

Such a speaker, however, needs a "baffle." It is obvious that while a region of condensed air is being created in front of the cone, a region of rarified air is set up behind it, and vice versa. To some extent the compressed air will move around the edge of the cone and counterbalance the rarified area behind. Low frequency sound will be more apt to do this than high frequency sound, since the low frequency waves spread around corners more easily. The higher frequencies tend to radiate in straight lines. Oper-

ating such a cone without a baffle results in the low notes more or less cancelling out, leaving a high-pitched, "tinny" sound. The baffle is a piece of very heavy paper board, or special thin wood, surrounding the cone on every side for a distance of several feet. This delays the sound, in its effort to move from the front to the back of the cone,

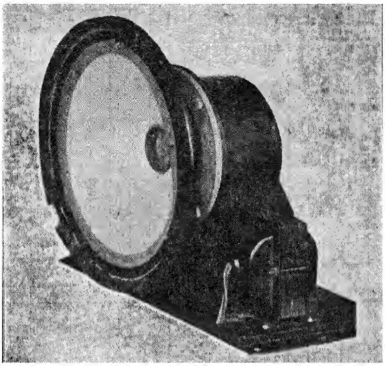


Fig. 68.—Jensen dynamic speaker as used by Royal Amplitone; baffle not shown.

sufficiently to destroy the interference effect. Housing the cone speaker in a box also works well. Double cones, of the type used with radios before the "dynamic" speaker became popular, and sometimes used in projection rooms as monitors, do not have this trouble; the back of the cone provides all the baffling needed.

"Exponential baffles," horn-shaped contrivances, are sometimes used with cone speakers to allow sound to be directed as necessary. We may regard the cone speaker as acting like the diaphragm of any receiver. It is placed at the narrow end of the "exponential baffle,"[1] which acts (so far as pointing the sound is concerned) like any horn.

There are two general types of horns. One is constructed of thin material, so put together and of such dimensions that the horn vibrates with all the frequencies being reproduced. The other type is very solidly made, for example,

[1] The term "exponential" refers to a mathematical formula for designing horns. An exponential horn is simply one whose dimensions agree with this formula.

by being cast of concrete, and does not vibrate with the sound waves passing through it. Obviously, only the first type is commercially practical.

It follows that, since a theatre horn must vibrate with the sound it carries and is very carefully designed toward that end, nothing should be done that will interfere with its motion to any degree. The horn is not to be repainted, for example. It should be hung in place only by the eye-bolts provided on it for that purpose. Wrapping ropes about its body may hinder the action. Glue or wood filler must not be used on it to any great extent without the advice of the manufacturer.

Impedance Match

Suppose an ordinary sound system, operating one loud speaker as efficiently as can be desired. Suppose the amplifier, as is often the case, has an impedance in its output circuit of 1,000 ohms. This amplifier feeds into an "output transformer" whose primary is wound for 1,000 ohms. The secondary of this transformer is wound to 16 ohms. The receiver unit likewise has a speech circuit impedance of 16 ohms. Here is a typical system.

Let us remove the output transformer and connect the receiver directly to the last tubes. Assuming the speech coil is not burnt out by the high plate voltage, the volume will be "down in the mud." When the transformer is restored, providing proper match between the output impedance of the amplifier and the impedance of the speaker, the volume returns to normal.

In a sound system properly designed there is only one point where impedance mismatch can possibly occur, and this is between the last amplifier and the speakers. The match here cannot be predetermined in the factory because the same amplifier may be used with one, or two, or any number of receivers, in different theatres. Some variable arrangement must be provided.

Perhaps the easiest way to describe what happens when impedances do not match will be to forget electricity for a

moment and consider some other things that apparently have no connection at all with impedances. Later on the connection will reveal itself.

The Analogy of Sound

It will be remembered that sound in a theatre is reflected by walls and other surfaces. But some of the sound also travels through the walls. Most probably it will be inaudible outside, unless exit doors are open, for theatres are substantially built as a rule. Everyone knows, however, that the noise of the projector mechanism can pass through the thinner wall of the projection room into the theatre, even when all doors are closed, and sometimes even when the ports are glassed in; and anyone who has ever lived in an apartment house is aware that a neighbor's family quarrels can often be heard through an unbroken wall.

Ladies living in apartment houses have been known to place their ears against a wall to hear such quarrels more distinctly. They realize that an ear pressed against the wall can catch the interesting details far more clearly than one inclined just an inch or so away.

But, leaving neighbors' family quarrels to such ladies as are interested, why is this so? The loss can not take place in the air; an inch, more or less, makes no similar difference in the intensity of sound in any other case.

Inside the room where the quarrel is going on some sound is penetrating the wall, and some is being reflected from the surface of the wall. The only way to explain a large loss of volume in an inch of air on the other side is to assume a similar phenomenon within the wall itself. Some of the sound in the plaster is penetrating the air of the next apartment, and some is being *reflected from the surface of the air*. That this is true will be clearer if we look into the very similar action of light. Meanwhile it may be noted that really sound-proof windows or projection room ports involve the use of double panes, separated by air, to increase the number of surfaces at which reflection can occur.

The Analogy of Light

A man can see himself in a windowpane because not all of the light striking that pane passes through it—some is reflected from it. If there is a strong light behind the window, he will not see the reflected image. It will be lost in the stronger light, but it is there just the same.

He can see himself in the surface of still water, unless there is strong light coming up from below the surface. In other words, not all the light that strikes the water penetrates it, some is reflected. Given a source of light under the water and darkness above, a fish would see his image reflected from the surface of the air. This actually happens in aquariums, where the top of the tank is usually in comparative darkness, while strong illumination enters through the glass side. In this case, not only the fish but the people who come to look at the fish see the finny reflections from the upper surface—and still, much light is escaping reflection; anyone looking down into the tank could see the fish quite plainly.

The projectionist who knows his optics understands this; he knows he must figure a loss of light for *each* surface of his lenses.

Water is transparent, and so is air; we may say that they each "conduct" light. They have different "indexes of refraction" or (may we say?) different impedances. When the light passes from air to water, or from water to air (or from air to glass or from glass to air), a certain portion is reflected.

Air conducts sound, and so do walls, these also have different "impedances," and a certain reflection of the waves takes place when the vibration passes from one to the other.

Reflection of Current

A speech current in an electric circuit is also vibratory; so that when it is fed from one impedance into another and different impedance a portion of the wave may be reflected

back toward its source. The extent of such reflection can be calculated; it increases with increasing mismatch of the impedances, and the current reflected is lost. With this

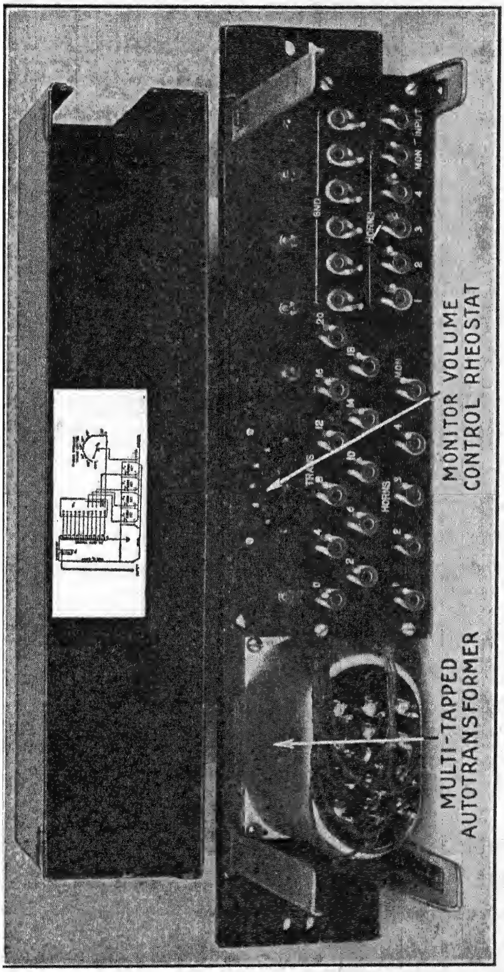


FIG. 69.—Rear view of Western Electric 209A panel (volume control) for matching the impedance of a number of 555W receivers. Note diagram on inside of cover.

clear, the reason for the loss in efficiency, in the imaginary case of a low-impedance speaker connected to an amplifier without a coupling transformer, is plain enough.

Mismatch Distortion

The air vibrations reflected from the walls of a theatre can set up distortion in the sound if certain contributing circumstances are present, as we saw in considering the acoustics of theatres; and it was noted that a number of contributing circumstances and a number of different forms of distortion were possible. Similarly, under suitable circumstances, which may or may not be present, electrical energy reflected from the "surface" of an impedance mismatch can create more than one kind of distortion. In every such case, the proper remedy is to correct the impedance match.

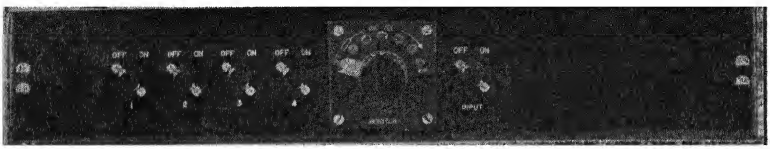


Fig. 70.—External view of Western Electric 209A panel **(volume control) as used with 555W receivers.**

Matching Speaker Impedances

A simple arrangement for matching speaker impedances to the amplifier is to provide an output transformer with the secondary tapped at a number of points. The impedance between any two adjacent taps may be 16 ohms (the usual speaker input impedance) and as many speakers as needed may be connected, one to each pair of taps. This is only one of a number of possible methods of matching impedance.

Another method that is a trifle more complicated is in common use and requires special mention for that reason. This involves the use of the horn-control panel that is part of the earlier Western Electric installations. In this panel the output transformer is an auto-transformer, that is, the primary and secondary windings are connected in series. In such a transformer there is only one coil, with separate taps for the primary portion and for the secondary portion.

In this particular horn control panel (Western Electric 555W) the transformer winding has seven sets of secondary

taps, allowing use of six stage speakers and a monitor. Each of these sets of taps consists of 11 connections to the coil; selection among which can be exercised by seven small knobs on the panel. These knobs perform the double function of acting as volume controls for each individual speaker and of matching the impedance. The advantage of having a separate volume control for each speaker is obvious; it helps in securing proper distribution of sound

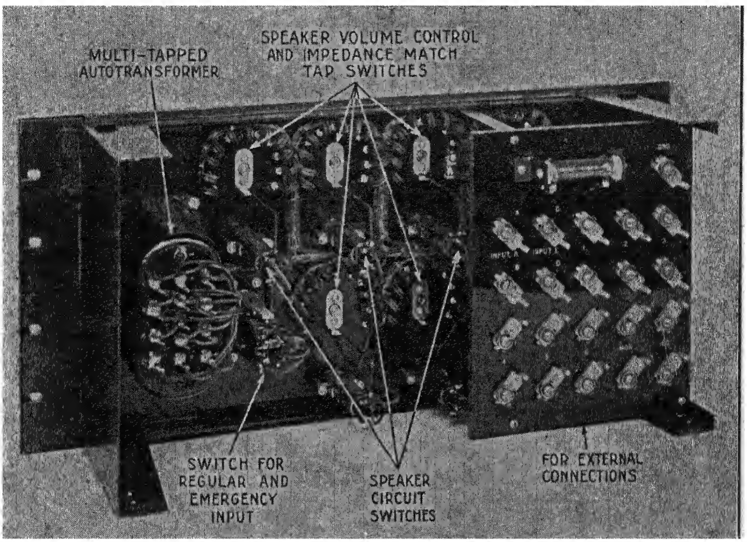


Fig. 71.—Rear view of Western Electric 200-A panel (output control) for matching the impedance of a number of 555W receivers, and for independent control of the volume from each.

in the theatre. An overall impedance match is secured when the separate transformer impedances, chosen for each speaker, add up to a total equal to the sum of the impedance of all the speakers used. Impedance match must, therefore, be taken into consideration in adjusting speaker volumes for distribution, but in practice the problem is not complicated. Where this type of horn panel is installed a simple code enables anyone to find a correct setting.

Fader Impedance Match

Consider the case of a fader which also serves to control the volume. Such a fader is a variable resistance. It would seem that whenever the fader setting is changed the impedance match between pick-up and fader and likewise between fader and amplifier, must be lost. Sometimes this is the case, when the fader does control volume by causing mismatch impedance losses. That can be done successfully where no appreciable distortion is likely to

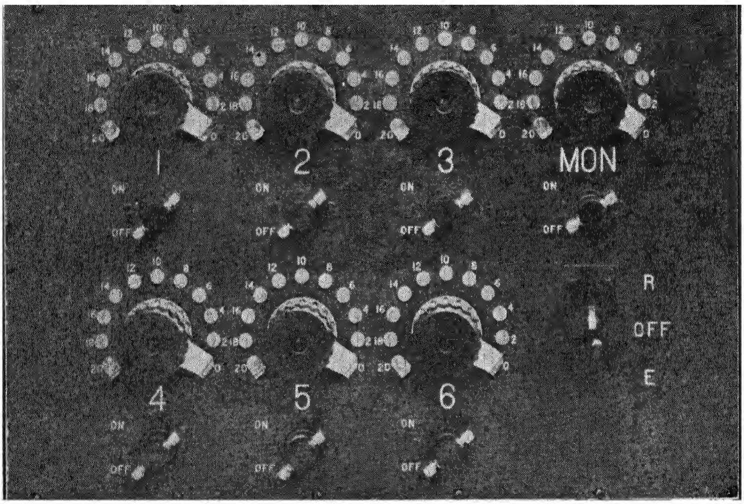


Fig. 72.—External view of the Western Electric 200-A panel (output control).

appear as a result. More often the fader is designed to offer constant impedance at any setting. There are a number of circuits which make this possible; all depend on some variation of the principle of compensating parallel resistances which by-pass part of the current at the same time that they make up for the change in the series resistance.

Volume Control

Many systems have, in addition to (or instead of) such a fader, a "gain," or volume, control. This may be used

to adjust the average output of the system to a point where the fader can most often be placed at a middle setting, thereby allowing the greatest possible fader range up and down to compensate for different audience conditions and for differences in recorded volume. In other systems it may be the only means provided for governing sound level. Such a gain control may be of the "constant impedance" type, but often is not; it is generally placed in the grid circuit of an amplifying tube. Since the grid circuit carries practically no current, its impedance is extremely high, and a small mismatch here is less important than elsewhere.

Ten Questions

1. When should a receiver unit, intended for use with a horn, be played without the horn?
2. Why?
3. Why does a cone speaker need no horn?
4 Why should a horn never be repainted?
5. What is most likely to be wrong with a dry rectifier that no longer passes sufficient current?
6. Why are filters seldom used in speaker field circuits supplied with rectified alternating current?
7. Why must impedances match throughout the sound system?
8. At what point in the system is mismatch most likely to occur?
9. Why?
10. What provision can be made for adjusting the match at that point?

Ten Answers

1. Never.
2. Without an air column to push against, the speech coil is liable to tear loose from its connecting wires, or otherwise ruin itself.
3. Because the larger area of the cone provides a sufficient air load.
4. Because it is carefully designed to vibrate with the frequencies it reproduces.
5. The nut that provides close physical contact between the treated copper discs and their connecting washers has loosened.
6. The field coil is itself an excellent inductive winding.
7. To prevent loss of efficiency and distortion due to reflection of current from the point of mismatch.
8. In the speaker circuit.
9. Because the manufacturer cannot always know how many speakers will have to be used with his amplifier.
10. An output transformer with several secondary taps to provide for fewer or more speakers; or such a transformer equipped with variable taps.

CHAPTER XI

MOTORS, GENERATORS, AND SPEED CONTROL

Motors and generators have been part of projection room equipment for many years; they need here, therefore, only such very brief review of the principles of their action as will be necessary for a more detailed discussion of those features that are peculiar to their use with sound equipment.

The loud-speaker unit is a motor; it uses electrical energy to create mechanical action. In the case of the speaker, the mechanical action is of the piston type. In the more familiar forms of motor, a rotary action is created, as being more desirable for most purposes.

Obviously, the difference between the piston action of the loud-speaker unit and the rotary motion of the ordinary electric motor is not great. One of the differences is that in most alternating current motors there are a number of "field coils" which are energized by the alternating current, the place of the speech winding in the loud speaker being taken by a number of windings that constitute an armature shaft. This shaft is so mounted as to be free to rotate.

One part of the action of such a motor is that of a transformer; current is induced in the armature windings, which act as a transformer secondary.

Since we now have in the field coils a number of electromagnets, and in the armature an alternating current, which happens to have been induced there by the transformer action of the device, the conditions necessary for creating mechanical motion are attained. In a properly designed mechanism of this kind the alternate attraction and repulsion between the field poles and the armature will have a rotary, or "torque," component, and the armature will revolve.

In the loud speaker motion is achieved because of the fluctuations of the current in the speech winding, and the motion therefore follows in frequency the frequency of the speech current. In an alternating current motor of the type just described the only fluctuations are those of the frequency of the alternating current supplied. Consequently the speed of such a motor—speed may quite properly be described as frequency of revolution—is directly dependent (for any given number of field coils) upon the

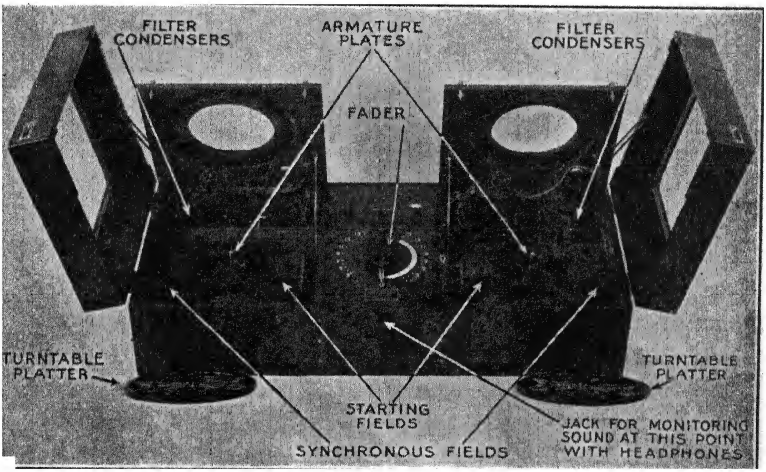


Fig. 73.—Western Electric type 203A reproducer set having double turntables driven by synchronous induction motors, in which the line frequency determines the speed, thereby attaining constant speed without a mechanical governor.

frequency of the alternating current that drives it. Such a motor may be constructed for any speed, and will maintain that speed constantly, despite rather wide variations of voltage and load, as long as the frequency supplied remains the same.

The simplest form of motor speed control for sound projection is therefore the use of a synchronous motor of this type.[1]

Such motors are frequently used for the non-synchronous turntable; and this involves a double application of the

[1] Synchronous, or in time with, the supplied frequency.

word "synchronous," which may mean either "in time with" the picture or "in time with" the frequency of the alternating current line.

For non-synchronous and other light work, the armature often consists of nothing but a toothed metal disc, which is set in rotation by the alternate attraction and repulsion of the alternating current supplied to the "field"; a special "starting coil" is sometimes added to help this attraction and repulsion take effect as torque, or rotation.

However, there is a slightly different form of synchronous motor, which involves the use of a commutator, and of that we shall speak in a moment.

Direct Current Motors

In an alternating current motor the frequency of the line supply provides that variation in current strength which is necessary to produce motion in a magnetic field. Direct current has no such variation; therefore the direct current motor must itself create a similar effect, and it uses a little apparatus called a commutator to that end. But even before this result is achieved, it is necessary to introduce current into the armature windings, or no magnetic relationship between armature and field will exist. Since the direct current will not provide transformer action, this current must be led into, and out of, the armature by a physical connection. But since the armature must rotate, the only connection possible is one in which a sliding contact, called a brush, presses against some sort of contact ring mounted on the shaft.

Now if this contact ring on the shaft is broken into a number of insulated segments, connecting to the loops of the windings on the armature, variation in the current flowing in the armature will be achieved.

At any given time only a few of the armature turns will receive maximum current; the commutator segments connecting to the other windings will not be in contact with any brush. The armature loops receiving maximum cur-

rent naturally move as close to, or as far from, the field coil affecting them, as they can. But the moment the armature turns, those loops lose contact with the brushes and others receive such contact; by this means the current flowing in the armature is continuously being shifted from one of its coils to another, and the motor continuously revolves.

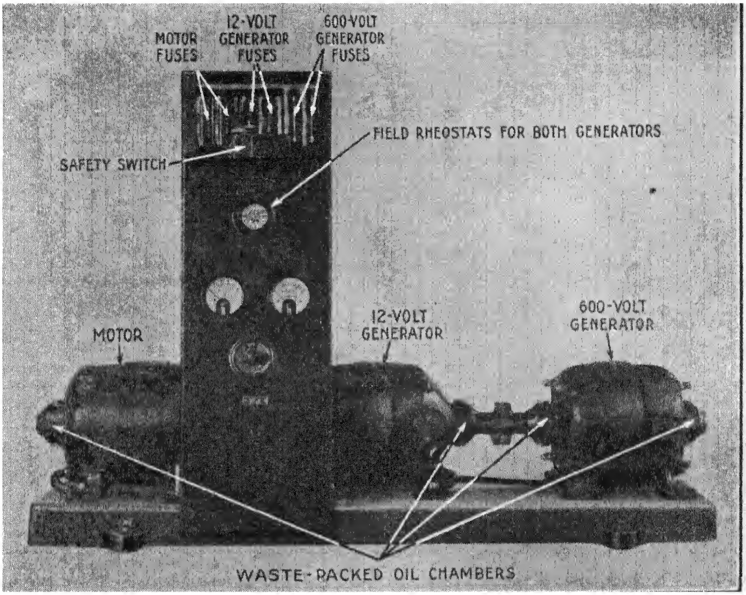


Fig. 74.—Alternating-current operated motor-generator set for RCA-Photophone PG-13 equipments.

Alternating current motors often have commutators also. Current received through these by the armature merely complicates the effect of the current that the armature receives by transformer action; and the interrupting effect of the commutator complicates the interrupting effect of the alternating current frequency; but in care and operation these motors are no more troublesome than any others. Depending on their construction, alternating current motors which are equipped with commutators may be

synchronous, in that their speed can bear a definite relation to the frequency supplied.[1]

Special Speed Controls

The motors driving sound projectors must always rotate at the same speed, regardless of fluctuations in the power line. If the speed varies with such fluctuations, unpleasant weaving, or hunting, effects will appear in the sound. Now the voltage of power lines will vary, and, consequently,

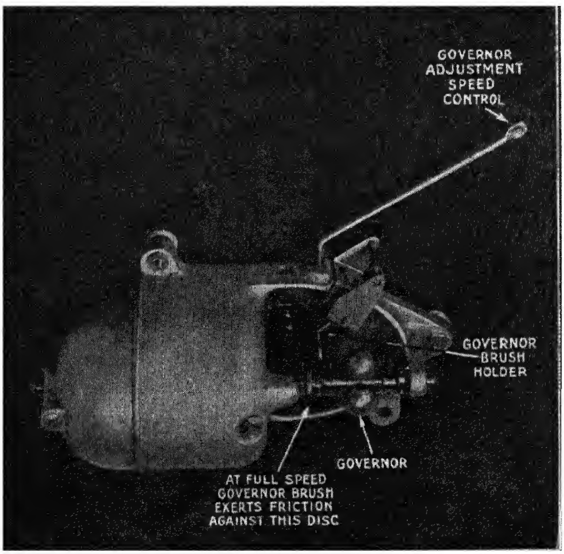


Fig. 75.—Driving motor with mechanical governor for speed control, used on earlier models of Western Electric non-synchronous reproducing turntables.

the current driven through the resistance of a motor will vary with it, but the frequency of an alternating current supply is usually maintained with a rather high degree of accuracy. Electric clocks that consist merely of a synchronous motor geared to the hands are now in wide-spread use, and as long as the voltage does not vary too much the frequency will keep them in time fairly well. Frequency-

[1] Many variations of these principles are used in commercial motors, unconnected with sound work.

controlled motors are coming into increasing favor for sound use. On the other hand, the fact that a synchronous motor clock keeps fairly good time may only mean that frequency fluctuations are present but average themselves out in the course of an hour or a day. There are places where the frequency regulation is not what it might be.

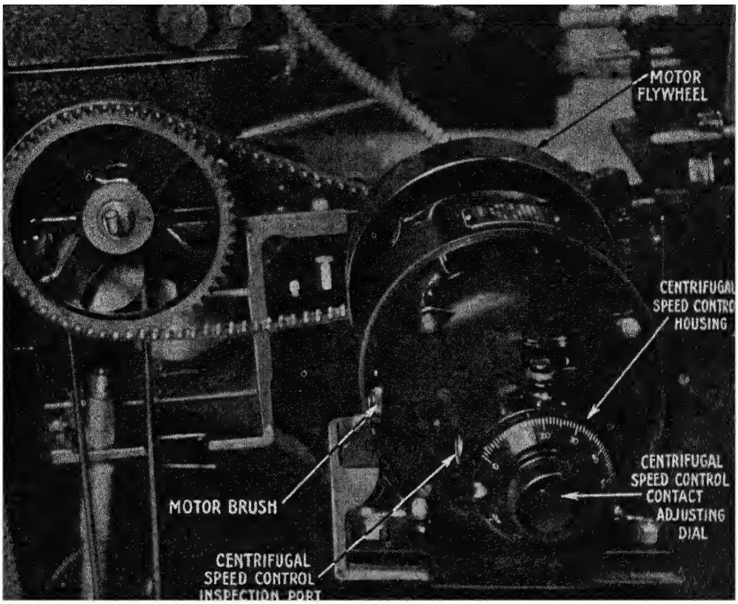


FIG. 76.—RCA-Photophone direct-current drive motor with automatic centrifugal speed control.

There are places where only direct current is available. Therefore several sound systems in widespread use employ other means of regulating projector speed.

THE GOVERNOR CONTACT

One such means, favored by R. C. A., involves provision of a mechanical governor, the action of which closes a contact when a predetermined speed is exceeded. The desired speed can be chosen by adjusting the position of the stationary contact. Closing this contact short-circuits

a resistance out of the motor-field supply line and thereby decreases the motor speed. As soon as the speed drops below what it should be, the contact opens and the motor speeds up again. There is thus a constant variation in motor speed, which has been found in practice small enough to be smoothed out by flywheels and mechanical filters.

A similar device, but one having a different purpose, is used in some synchronous motors, of the kind that will not start by themselves, but will continue running once some influence starts them. A separate starting field is provided for such motors, and when proper speed is reached, a contact mounted on a mechanical governor removes the starting field from the circuit. In other synchronous motors of this type, the starting field remains in operation as long as the motor runs. In a light motor this introduces no serious complications. A starting field device of this kind, it must be remembered, has nothing to do with speed control, which is governed only by the supplied frequency. A very similar contrivance can thus be used in two different ways, and the reader who has that arrangement in his own projection room must find out for himself what it is being used for in his case.

The Bucking Generator

Another method of control is that of mounting a generator on the same shaft with the driving motor. The torque of the generator acts to reinforce the motor torque below "normal" speed (1,200 r.p.m.) and to oppose the motor torque above that speed. In addition, current created by this generator opposes the line current that drives the motor. When the motor turns too fast, the generator current increases, resistance to the line current increases accordingly, and the speed drops; when the motor turns too slowly, the generator resistance to the line current decreases, and the motor speeds up.

The same device may be used in another way, in motors so designed that under normal conditions an increase in the field current cuts down the speed. How this can happen

we will see later on; but in such motors the generator works with the line supply, instead of opposing it, increasing the field current in order to cut down speed when the motor turns too fast, and decreasing the field current in order to raise the speed when it turns too slowly.

This arrangement is the principle used in the newer Western Electric systems, where the motor "control box" consists chiefly of a large condenser which is used to "phase," or time, the motor-field current with the alternating-current line supply.

Vacuum Tube Control Boxes

The older Western Electric systems have control boxes involving vacuum tubes and a rather complicated circuit. There are four types of this circuit in commercial use; two for alternating current and two for direct current.

An alternating current generator, whose output is somewhat arbitrarily chosen to be 720 cycles, is mounted on the same shaft with the motor armature. The current created by this generator is fed into the control box, where it passes through a filter tuned to that frequency. The action of this filter is to alter the grid bias of a vacuum tube when the motor changes speed; the consequent change in plate current through that tube is applied to the grids of two others, and the plate current from these varies the supply to the motor. The action differs greatly in detail in each of the four types of box now in use, but the principle here outlined is common to all.

The circuits of these boxes are such that comparatively few things which may happen to them will prevent the motor from running, but even the smallest trouble may result in loss of proper speed, or total loss of control. Total loss of control suggests a serious condition such as a short circuit or a ground somewhere in the box, which can be traced down by following out the circuits with a battery and a high resistance voltmeter. Improper speed suggests a defect in the filter connections, which may be in the filter proper or in one of the resistances that are associated with

it in a balanced, or "bridge," circuit. A defective tube which fails to respond accurately to changes in its grid bias may also cause the trouble; the tube whose grid is most directly connected to the filter is in the most sensitive position and, therefore, the most likely to be at fault.

Some of these boxes are arranged with a tapped resistor whose value can be varied to compensate for any departures from proper line voltage which may be serious enough to overcome the regulating action and to affect the speed; wherever line voltage has changed materially from what it

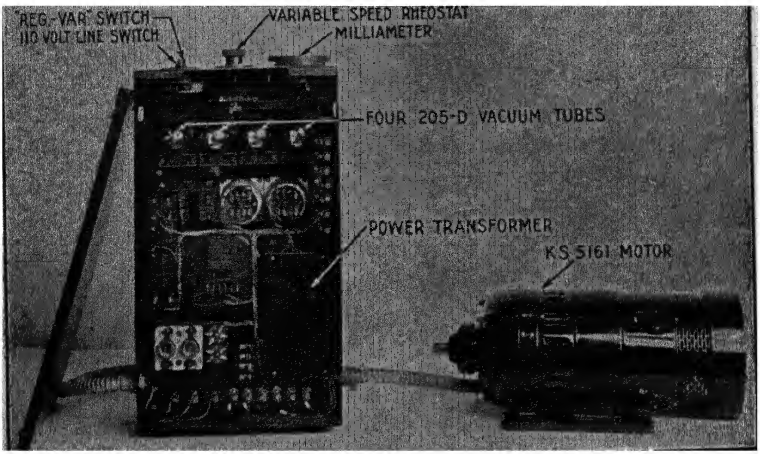


FIG. 77.—Western Electric 708A control cabinet (alternating-current control box) with KS5161 motor.

was when such a box was installed, the resistor may have to be varied accordingly.

The most intimate knowledge of the circuits and functioning of such boxes is hardly of much more value in locating their faults than some little experience with them and application of the old method of trial and error. The suggestions given above cover the ways in which they most commonly give trouble. But in view of their cost and their delicacy, projection-room repairs are inadvisable except in cases of urgent necessity.

Generators

The fundamentals of generator operation were fully covered in connection with the disc reproducer, but a number of variations appear in the practical construction of generators for power purposes.

Any motor is a generator; if it is caused to rotate by application of mechanical power, current can be drawn

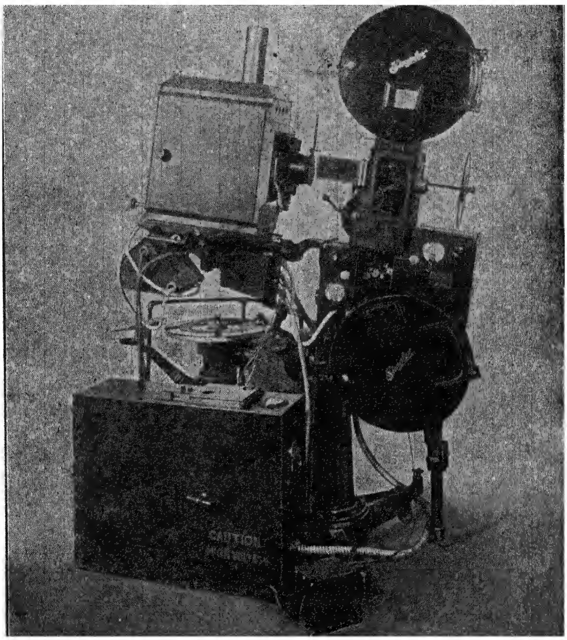


Fig. 78.—Western Electric D 86012 film-reproducing attachment with 700-A control cabinet (direct-current motor control box).

from its terminals. When it is used as a motor and made to rotate only by application of current, it still is a generator;[1] new current is created in its armature, and this opposes the flow of the current supplied. The stronger the field current, the greater the "counter voltage" that will be generated in the armature. This is the reason why increasing the field current will slow down, and not increase, the motor

[1] The device called an "alternator," which uses the same windings for two purposes, is based on this generating action of motors.

speed. A generator may have a commutator; or if alternating current is to be drawn from the armature, the brushes may rest against continuous "slip rings."

Special types of alternating current generators, such as those most commonly used for motor speed control, use a modification of the same principle of varying a flux path that is employed in one type of disc reproducer. An irregularly shaped metal disc, mounted to turn with the motor shaft, periodically introduces its projections into the path of magnetic field, provided by a winding and a core. An alternating current will then be set up in a second winding on the same core. Such an arrangement has the advantage of needing no brushes at all.

Sound Troubles Due to Motors and Generators

Commonly, there are only two parts of any motor or generator that need particular attention. One is the bearings in which the shaft turns; these require only the same care of lubrication that any mechanical bearing calls for; in every case the manufacturer's instructions are the safest guide.

The commutator is the other. Since it is made of copper, a soft metal, it wears with use. It is pitted by imperceptible sparking which is caused by very slightly imperfect contact between itself and the brushes; the brushes themselves wear and impair the contact accordingly. Often the mica insulation between the segments wears less rapidly than the copper and the contact is still further weakened.

All of these things happen to all commutators, and, according to the case, require reseating the brushes, sandpapering the commutator, undercutting the mica, or taking the whole shaft out, and turning the commutator down on a lathe. If they are anywhere near a sound installation, commutators will need more care than ordinarily, because bad contact can result in relatively minute sparkings that are picked up by the system and appear in the speakers as noise.

Readiness in Starting

Many projector motors can be cured of starting slowly by shifting the brushes through a small angle. This alters the relation between the magnetic fluxes of the armature and of the field-pole currents, and provides a stronger torque.[1]

Review

An electric motor of ordinary construction revolves by virtue of the interaction between the magnetic field provided by field windings and that created by the varying current flowing in an armature.

The armature revolves, and, therefore, any current appearing in it must be introduced there either by transformer action from the field or by a sliding contact provided by brushes.

In a direct current motor, fluctuation of the armature current is secured by having the brushes slide over a commutator, which consists of a number of insulated copper segments connected to the loops in the armature winding. As one loop is attracted to, or repelled from, a field pole, the commutator, revolving with the armature, disconnects the brushes from that loop and energizes another.

In alternating-current motors, the frequency of the supply, whether it is complicated by a commutator action or not, will govern the action to such an extent that motors can be wound to rotate at any given speed for any given frequency, provided the voltage of the supply remains constant within fairly liberal limits.

Such alternating motors are called synchronous because their action is "in time with" the line frequency. For light work their armatures may consist of nothing more than a toothed metallic disc, acted upon by a periodically reversing magnetic field.

[1] Caution should be exercised in shifting motor brushes, since too strong a starting torque can do serious damage to the motor and to the projector.

Synchronous motors which work on this principle are often used to provide a constant speed drive for sound projectors and non-synchronous turntables.

Speed Control Devices

One of these consists of a mechanical governor whose action closes a contact when the motor runs too fast, thereby changing the current supply to the motor and so reducing the speed. Commonly these contacts "chatter," and the rapid variations in motor speed resulting are smoothed out by flywheels and mechanical filters.

Another type of speed control employs a generator mounted on the shaft of the motor and turning with it. The output of this generator constitutes part of the motor's current supply, either opposing or reïnforcing the line current, according to the design of the motor; in either case the generator output varies with any change of speed in such fashion as to counteract that change.

Speed control boxes embodying vacuum tube circuits are built in a number of different models, involving many variations of detail, but all depend on the same principle of an alternating current generator mounted on the motor shaft, whose output—720 cycles—is fed through a frequency filter, and, in combination with the filter, alters the bias of a vacuum tube whenever the motor speed changes. This alteration in bias is amplified and used to alter the current supply to the motor.

Trouble in these boxes is still traced chiefly by the method of trial and error, with some guidance from experience. A defective tube, especially the tube whose bias is directly controlled by the filter and is, therefore, the most sensitive, is one thing to look for; a short circuit in the filter, or in one of resistances that balance it in a "bridge" arrangement is another. Total loss of control will generally be found to be due to a short circuit or a ground. Regulation at the wrong speed can be corrected in some of these boxes by adjustments to a tapped resistor.

Generators

A generator may be substantially an ordinary motor, driven mechanically instead of electrically and creating electric current instead of mechanical rotation. Any motor is in itself a generator, the current created in it opposing the driving current and so acting as a brake upon the speed.

A direct current generator will supply current through a commutator, exactly as a direct current motor is fed by a commutator; the brushes of an alternating current generator may slide over continuous "slip rings."

Special forms of alternating current generators rely on the action of a varying magnetic flux; they periodically introduce projections of a metal disc into a flux path, thereby changing the strength of the field and so generating alternating current in a motionless armature winding.

Commutator Care

Because irregular commutator contact may create slight sparkings that will be picked up in the sound system as noise, unusual care is needed for motors operating in connection with, or even in proximity to, sound equipment.

Slow Starting

The starting time of a motor can often be changed by adjusting the position of the brushes on the commutator to secure stronger, or weaker, initial torque. In some types of Western Electric control boxes adjusting a tapped resistor will also alter the starting speed.

Ten Questions

1. Why can a synchronous motor be used to drive sound projectors without other speed control?
2. On what form of current can it not be used?
3. Name three methods of controlling speed which can be used on any type of current.
4. What is most likely to give trouble with the first?
5. With the second?
6. With the third?

7. Why does a motor commutator need special care from the point of view of sound equipment?

8. What remedy can often, but not always, be applied to projector motors slow in starting?

9. What is the difference in principle between a motor and a generator?

10. On the basis of your answer to the last question, could a telephone receiver be used as a microphone?

Ten Answers

1. Because such a motor will maintain a constant speed—if voltage or load do not vary too greatly—as long as the supplied frequency remains constant.

2. Direct current, which has no frequency, but is a smooth flow.

3. A mechanical governor closes a contact when speed is too high, and so alters the current supplied. A generator is mounted on the same shaft as the motor and feeds into the motor supply line, compensating for changes in speed by corresponding changes in its output and in its torque. A generator whose output passes through a frequency filter to change the bias on a vacuum tube grid with change of motor speed; this grid change being amplified and used to control the motor current supply.

4. Defective or dirty contact, or mechanical defect in the governor.

5. Only the ordinary ills common to all motors, such as bad brushes or bearings.

6. Defective vacuum tube; ground or short circuit in any part of the control box; short circuit, open circuit or other defect in the filter or in other apparatus associated with the filter in a balanced circuit.

7. Because very slightly bad contact there can set up "commutator ripple" in the sound.

8. Shifting the brushes.

9. Only that one is driven by current and produces motion, while the other is mechanically driven and produces current.

10. Yes. So can most loud speakers. The condenser microphone, also, would work, theoretically at least, as a receiver, but the carbon button microphone would not.

CHAPTER XII

CARE OF SOUND EQUIPMENT AND PRECAUTIONS TO PREVENT TROUBLE

Like any other machinery, sound equipment needs certain definite care and the use of certain definite precautions. Many steps, both of care and of precaution, have already been explained in connection with individual parts of the installation. Cleanliness is one precaution that cannot be overemphasized.

There are two good reasons for keeping sound equipment spotless. The obvious one is to prevent the troubles caused by uncleanliness, such as scoring of bearings by grit, development of high resistance in sliding contacts because of dust, swelling of the rubber mat under the photo-cell amplifier (in some types of equipment) because of excessive oil—or any of a thousand others.

But the second reason for cleanliness, which is the psychological reason, is infinitely more important. The good mechanic knows this reason well even if he has never put it into words—he feels it. Clean and well-kept machines breed confidence in those who operate them. Possibly this may be unjustified confidence; but, nevertheless, confidence, the sense of being master of a situation, is always indispensable. One who is working with dirty and uncared-for equipment is constantly haunted by the fear that it may give trouble at any minute, for he never knows what is happening under the dirt. The fear may be unjustified, but it is there, and when something does go wrong, the same feeling prevents prompt and efficient steps toward a remedy. In fact, the most efficient way to remedy trouble with neglected equipment is to start by giving the part affected a good cleaning. The psychological handicap arising from the use of dirty machinery is like the psycho-

logical handicap arising from the use of poor tools—no really good workman wants either.

Reminder Forms

Any business office will have a number of printed forms provided, often at considerable expense, for the purpose of reminding somebody of something. You may find it to your advantage to draw up a few such forms for yourself—they will not need to be printed. Let one cover a daily, a second a weekly, a third a monthly, and a fourth a semi-annual inspection of your sound mechanism. This scheme has been known to work very well where the forms are fitted to individual installations.

With such a form, pasted on a bit of cardboard for permanence, the projectionist goes over his equipment, noting on a scratch pad everything he finds that needs attention. When the inspection is over, he goes back to the matters he has noted, and takes care of them. Many troubles are cured this way before they become important.

The Disc Pick-up

The disc pick-up was fully covered in the chapter on the mechanics of disc reproduction.

The Film Pick-up

The film pick-up was largely covered in the chapters on this pick-up and its mechanical requirements, but matters that might stand further mention include the following:

Where the head has to be "shimmed up" to receive a floating shaft, periodical checks should be made to see that this shaft still fits properly. These should be made daily for the first few days, then weekly for several weeks, and thereafter monthly.

Microphonic tubes are especially to be guarded against. Before any tube is set aside as fit for use in the photo-cell amplifier, it should be tested, against a tube which is known to be satisfactory, in this way: install the new tube in the first socket temporarily and flick it with your finger

nail. It should not create more noise in the monitor than the satisfactory tube does. If it does, test it similarly for

PRODUCER	NAME OF SUBJECT	QUALITY	VOLUME	SURFACE	FADER	SETTING OF HORNS					
						UPPER			LOWER		
						L	C	R	L	C	R

BATTERY AND CHARGING

BATTERIES	A 1	A 2	H 1	H 2	F 1	F 2	WET B BATTERY
HYDROMETER READING							
ELECTROLYTE LEVEL							

BATTERY TOPS CLEAN		TERMINALS VASELINED		CONNECTIONS TIGHT	

AMPLIFIERS AND RECTIFIER (CHECK WHICH ONE OF THESE INSTALLED)

	46 A		46 B		8 B		9 A		10 A		6000 RECT		41 A		42 A		43 A	
	REG	EMER	REG	EMER	REG	EMER	REG	EMER	REG	EMER	REG	EMER	REG	EMER	REG	EMER	REG	EMER
FILAMENT VOLTS																		
FILAMENT AMPERES																		
PLATE VOLTS																		
PLATE MILLIAMPERES																		
TUBES REPLACED																		

TURNTABLES	PROJECTORS 1	2	3
LEVEL			
SPEED			
RUBBER CONNECTION			
ALIGNMENT STRAIGHT			
VIBRATION			

REPRODUCERS	PROJECTORS 1	2	3
ARMS LEVEL			
REPRODUCER DRIFT			
NEEDLE HOLDERS			
CONNECTIONS			
MATCHED FOR EQUAL VOLUME			

RECEIVERS (HORNS) EQUAL VOLUME WHEN PLACED AT ZERO			
	LEFT	CENTER	RIGHT
UPPER			
CONN TIGHT			
	LEFT	CENTER	RIGHT
LOWER			
CONN TIGHT			

SPARE PARTS	
SPARE PARTS CHECKED	
SPARE PARTS USED	
SPARE PARTS NEEDED	
SD ORDER No	
DM TICKET No	

PROJECTION	
PICTURE STEADY	
VIBRATION IN PROJECTOR	
PICTURE SHEET (KIND)	
PICTURE SHEET CONDITION	
TAKE UP CHAIN - CONDITION	

NON-SYNCHRONOUS EQUIPMENT	LEFT	RIGHT
TURNTABLE LEVEL		
SPEED NORMAL		
REPRODUCER ARM SWINGS CLEAR		
GAUGE CLEAR OF CONTACT		
NEEDLE HOLDER CONDITION		
REPRODUCERS MATCHED		
FADER CONDITION		
CONNECTIONS TIGHT		
MOTOR FREE FROM SPARKING		
MOTOR RUNS FREE AND QUIET		
GEARS QUIET		
MOTOR GREASED		

GAIN CONTROL SETTING		VOLTAGE FILM B BATTERIES		
REGULAR	EMERGENCY	1	2	3

GRID (C) BATTERY VOLTAGE BETWEEN CONTACT STUBS				
	0	0	0	0
8B				
9A				
10A				

FILM AMPLIFIER AND PICK UP	PROJECTORS 1	2	3
PHOTO ELEC CELL CORR PLACED			
EXCITING LAMP CORR FOCUSSED			
EXCITING LAMP FIL STRAIGHT			
EXCITING LAMP NOT DISCOLORED			
FILM SOUND GATE CLEANED			
FILM CENTERED ON SLIT			
SOUND GATE SEATING PROPERLY			
MILLIAMETER READING (270 MILS)			
EXCITING LAMP ' (3 6 AMP)			
CONDITION OF TUBES			

MOTOR AND CONTROL CABINET	PROJECTORS 1	2	3
CONTACTS CLEAN			
APPEARANCE OF TUBES			
OPERATES—NORMALLY			
FLYWHEEL TIGHT			
UPPER GEAR BOX QUIET			
LOWER GEAR BOX QUIET			
RUNS WITHOUT VIBRATION			
SET SCREWS TIGHT			

ROUTINE TROUBLES CLEARED

REMARKS: SOUND DISTRIBUTION IN THEATRE, MANAGERS COMMENTS ETC

FIG. 79.—Typical service form covering details of an inspection. (Since this form applies to many types of equipment a form for an individual installation would be very much simplified.)

use in the second socket, and then in the third (if there is one). Any tube of standard manufacture can be returned

to the maker for free replacement on the ground that it is too microphonic.

B batteries should be carefully checked and discarded when they have fallen below a definite voltage. Low batteries are very apt to be noisy. Many of the larger theatres set 85 volts at no load as the standard below which 90-volt batteries are discarded. Reasons of economy may indicate longer use in your own house, in which case you can test doubtful batteries by disconnecting them from the circuit and listening to them with a pair of *good* headphones. (Phones of about 2,000 ohms resistance.) Fasten the phone tips firmly to the battery for this test. Do not merely hold them against the studs or your "body capacity" will affect the result. Any battery which shows the slightest noise on this test should be discarded.

In buying B batteries, be sure that they are new—that they have not had a long shelf-life.

Fader, Switches, and All Variable Contacts

Cleanliness, and then more cleanliness, is the only care needed in most cases. If your system uses "anticapacity" switches or relay contacts—these have long, flexible prongs, somewhat like the prongs of a phone jack—leave the prongs entirely alone. Straightening them after they have once been bent is almost impossible without special tools, and if they are bent, they consistently cause sound to "go out" by making poor connection. In cleaning the contact points be very careful not to bend the prongs.

The Amplifier

Watch for signs of overheating in transformers and condenser banks. In many cases these devices will contain tar for insulation. When the tar starts to melt and run out, overheating is indicated. Sometimes this means an overload to be found and corrected (perhaps owing to excessive line voltage). Sometimes it merely means that the device which is overheating is not as perfectly designed for its work as it might have been. Sometimes serious

trouble, such as a high resistance short circuit or a defective tube, is indicated. If no trouble can be found and line voltage is normal, you can forestall trouble by replacing the part in question. If you do not do this, at least provide yourself with a spare for it, and for any others (study your amplifier drawing) that are likely to be damaged as a consequence of its breaking down.

Tubes

A tube short-circuited internally causes no end of trouble. Since the grid is centrally located between the two other elements, such a short circuit always is grid-to-plate or grid-to-filament, and, in very severe cases (for example, when the tube has been dropped) both may exist.

Considering only the milder cases, it is clear that when the grid short-circuits against another element within the tube, its bias, and therefore its ability to control the plate current, is destroyed. A highly excessive plate current may flow in consequence, and perhaps burn out a power transformer. Carefully examine any tube that has been dropped, and test through it with voltmeter or headphones if you are in doubt, before putting it in any socket.

Grid-filament Short Circuits

One special case of such short circuits can stand an extra word—it is a grid-to-filament short circuit that occurs only *after* current is turned on the tube. In tubes which are comparatively long and slender, it calls for an extra precaution.

The filament of a tube expands with heat. Most heated objects act in the same way. Concrete roads are ribbed with tar-filled cracks, so that summer expansion will not break up the concrete; steel bridges and railroad tracks are arranged with end-play to allow for the effects of warm weather. This is why the butt-end joints of rails are noisy under the wheels. When the filaments of all tubes expand, they are doing nothing unusual.

The grid and the filament, being conductors spaced by an insulating medium, may be regarded as two plates of a charged condenser. An attraction exists between the opposite charges, tending to draw the grid and filament together; therefore any "slack" in the filament bulges outward toward the grid. In long tubes the length of the filament and the spacing of the elements are such that this bulge may extend far enough to allow filament and grid to touch.

In order to prevent this, springs are mounted in the tube at its upper end, which pull against the expansion of the filament, preventing any slack. The expansion of the springs can be plainly observed when a cold tube is first lit. Careful watch should be kept on this spring action before any new tube is accepted as fit for use. *If the springs do not expand* cut your power switch, *never turn plate current on that tube.* Old tubes should be watched occasionally for the same action.

These springs can be seen working, of course, only when the tube has been turned off long enough for the filament to be quite cold.

Matching Tubes

Matching tubes is important in the case of push-pull amplifiers and full-wave rectifiers.

In these circuits each of the two tubes is intended to carry just half the load. If one is low in emission, the circuit is such that the other tube will tend to carry most or all of the same current load.

In amplifier circuits this will lead to distortion, since the tube that is doing the work is overloaded. In rectifier circuits the results can be even more serious.

In a full-wave rectifier the transformer secondary will have a center tap; each half of the secondary supplies one tube. If low emission causes one tube to carry more than its share of the load, the transformer winding which feeds that tube will likewise overload. Some transformers now used in sound work happen not to be designed with a suffi-

cient safety factor to withstand the effects of mismatched tubes. The burning out of transformers owing to this cause, and consequent closing of a theatre for a prolonged period have been all-too-frequent occurrences in the past.

Your full-wave rectifiers may be equipped with meters which allow you to read the plate current flowing in each tube. Balance these readings by trying different tubes until you get matched pairs. Or perhaps only one meter is on the panel, reading the combined current drawn through both tubes. Raise one rectifier tube from its socket, momentarily only, just long enough to see how far the meter changes. Do the same with the other tube. Arrange pairs of tubes that will give the same meter change for both.

It will not matter if rectifier tubes are weak, as long as they can pass enough current to keep the amplifier working at the proper volume of output; but in full-wave circuits one must be as weak as the other.

Tube Contacts

The contacts between the studs on the tube base and the prongs in the socket give rise to serious troubles. With the smaller tubes, these are largely confined to loss of sound, due to dirt in such contacts. The socket prongs may be cleaned with the red rubber eraser on the end of a pencil. The tube studs can be cleaned with carbon tetrachloride.

With the larger tubes, dirt does not often cause loss of sound, except when it finds its way into a grid contact, and not always even then. But it does cause small sparking in one of the power circuits, especially the filament circuit, which for the larger tubes may have low voltage and comparatively high current. This condition and a bit of dirt on the prong make for a small, continuous arc, which burns the prong and melts the solder on the tube stud, resulting in a still poorer contact and larger arc, and so on. In the end, both tube and socket have to be thrown away.

All tubes should be removed once a month, and the sockets examined for evidence of clean contacts; in the larger sockets evidence of arcing should be looked for. If this

condition is found, the socket prong should be removed and sandpapered smooth, and the tube stud likewise smoothed down, with either sandpaper or a soldering iron. The soldering iron should always be used whenever sandpapering is likely to make that stud shorter than the others and, therefore, to create a new cause for imperfect contact.

Loud Speakers

Wherever a number of receivers are supplied with field current from a set of batteries, a rectifier, or a motor generator, periodic checks should be made to insure that this current remains at the proper value. If too little current is supplied, volume will drop off, but the effects of too much current are far more serious. The field winding may overheat and burn out; or the heat surrounding the speech coil may help that to burn out, especially if it is already overloaded. In one make of receiver, this excessive heat has been known to melt the cement that fastens the speech coil to the diaphragm sufficiently for these two elements to come apart and render the unit worthless.

If the horns or other speakers are to be struck to make room for vaudeville, careful marks must be provided to make sure that they are properly replaced, otherwise distribution will suffer. But stage crews are also human. In such houses, especially if directional horns or baffles are used, careful check must be kept upon distribution at all times.

Storage Batteries

The storage battery is a complicated chemical system and, therefore, needs care against the introduction of foreign chemicals that may upset its action.

This involves first of all scrupulous cleanliness. The top of the battery should be kept clean and dry at all times. (Another good reason for this is that wet battery tops allow a small current leakage that in the end means some months of shorter life.) Acid accidentally spilled while taking hydrometer readings should be neutralized with ammonia

water, and then wiped dry. Many projectionists still seem to overlook the necessity for caring for the tops of their batteries.

Copper wire should not be scraped near enough to the battery for fine filings to get in at the vent.

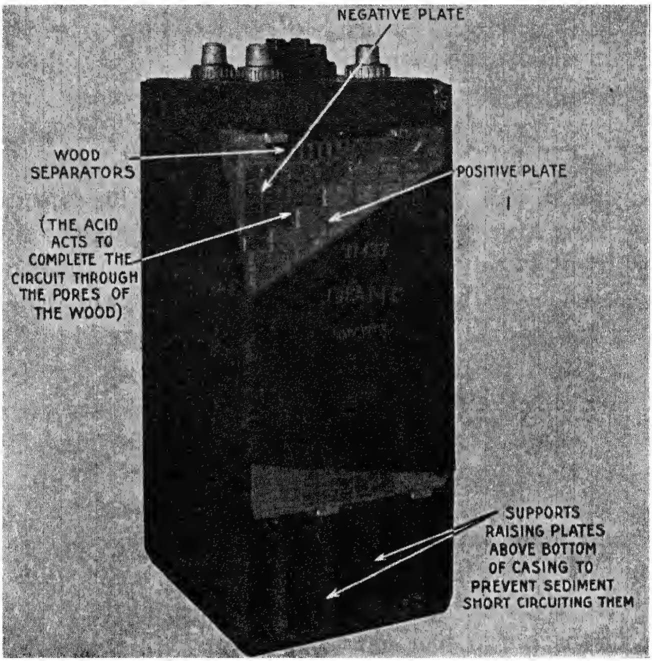


FIG. 80.—A storage battery cut away to show the internal construction.

Pure distilled water should be used for refilling the cells; otherwise imperceptibly small amounts of metal, which may be present in such small quantities that the water is quite fit to drink, can accumulate and with time can seriously upset the proper chemical action.

The greenish-white deposit (sulphate of copper) which collects on the exposed terminals should be thoroughly cleaned away as fast as it appears. It corrodes the wire leading from the terminal, and so reduces its carrying capacity; and it intrudes between that wire and the lead and makes for poor contact, resulting in noisy sound. This

deposit is due to acid from the battery reaching the copper wire and reacting with it chemically. If the terminals are kept properly covered with vaseline or "non-oxide grease," this deposit will never appear. When it does appear, care must be taken that in cleaning it off none of it drops into the cell.

Batteries must not be kept in any extremely warm place, such as the same room with the arc circuit rheostats. Overheating of the battery from any cause results in flakes of "active material" falling from the lead framework of the plates. This shortens the life of the battery, while collection of scraps of such material at the bottom of cell may pile up until the plates are short-circuited. Among other troubles, overheating also decomposes the wooden separators used between the plates. Overcharging the battery results in overheating. For this reason the charging rate[1] specified by the manufacturer should never be exceeded except in emergency. For the same reason the batteries should not be left on charge all night unless the rate has been very exactly calculated to guard against overcharge.

If it is necessary to charge at night, take steps to ascertain the proper rate. The manufacturer of your batteries will probably be willing to provide you with a chart designed for them, showing the correct current, according to every state of discharge read on the hydrometer and according to the number of hours during which the charge will be unsupervised.

Undercharging, on the other hand, creates other troubles. Accurate charging is the only answer.

The solution in the cells must be kept at the proper height—just high enough to cover the plates, and no higher. It will naturally evaporate faster, and will therefore need more attention, in summer than in winter. Care must be taken, while making hydrometer readings, to see that the solution for each reading is returned to its proper cell; otherwise one will permanently read lower than another.

[1] The amount of current flowing into the battery.

In general, hydrometer readings of all cells which are in the same circuit, and therefore receive the same use and charge, should correspond; but occasionally, because of unequal filling and possibly loss of some electrolyte (for example, through carelessness with the hydrometer) a discrepancy will creep in. However, when voltage readings per cell (taken while the battery is either in use or on charge) correspond with hydrometer discrepancies, trouble is indicated. In a case of this kind prompt servicing may prolong the life of this piece of equipment.

Review

Preventing trouble involves, first of all, having the equipment always fit—in such condition as to give a minimum of trouble and to allow any trouble that does occur to be found quickly. This calls primarily for cleanliness; which has the further, psychological, advantage of keeping not only the machine but the operator of the machine in the best possible condition, at all times, for successful work.

Routine Inspection

Routine inspection keeps the equipment in good shape and reveals little troubles before they become big ones. It is greatly helped by reminder forms that prevent anything being overlooked.

Disc and Film Pick-up

Disc and film pick-up were thoroughly covered in the chapters dealing with those portions of the equipment. These may advantageously be reviewed here.

Microphonic Tubes

Microphonic tubes should be guarded against by checking all small tubes for this trouble before they are set aside as fit for use. The noise set up in the monitor, when the tube under test is tapped gently, can be compared with the similar noise created by a tube which is known to be satis-

factory; or the system can be operated in the usual way with the new tube in use, and the "background noise" then existing carefully noted.

Faders, Switches, and Variable Contacts

Faders, switches, and variable contacts require scrupulous cleanliness. The current in most of these is very low, and small bits of dirt can create large amounts of noise, or even stop sound altogether. In cleaning contacts with long, springy prongs, great care must be exercised that these are not bent in the least degree, or contact will be imperfect thereafter.

Amplifiers

Amplifiers call for careful check of all parts that are likely to overheat, especially transformers and condensers. Where overheating exists and its cause cannot be found and removed, it will often be best to order spares against a possible emergency. Such spares should include any part of the circuit which is likely to be burnt out if the overheated part breaks down. Where an interruption to the show is regarded as more important than considerations of economy, the part in question should be replaced immediately.

Loud Speakers

The current supplied to the field windings should be checked periodically to prevent an oversupply that can work serious damage of several different kinds to the unit.

Distribution should be carefully watched wherever speakers are struck for vaudeville, unless their mounting is such (as when they ride with the screen) that they cannot possibly be returned to an incorrect position.

Storage Batteries

Storage batteries demand chemical cleanliness. Their tops must be kept clean and dry, both to avoid impurities

ultimately entering the cell and to prevent small leakage currents that, in a matter of years, mean a substantial shortening of the battery's life. Any acid spilled on the top of the battery should be neutralized at once with ammonia water, and the top then wiped dry.

The greenish sulphate-of-copper deposit that forms on the terminals may cause a bad connection, and hence noisy sound. Its appearance can be prevented by protecting the copper wire against any contact with the acid; vaseline or "non-oxide grease" is used for this. Care must be taken in cleaning off any such deposit that none falls into the cell.

Overheating of any kind, whether due to having another source of heat in the same room or to overcharging, is very bad for the battery. The charging rate must therefore be very carefully regulated whenever the battery is to be left on charge without supervision. Tables showing the correct rate for all possible circumstances can often be obtained from the manufacturer, and will help materially to prolong the battery's life.

Hydrometer readings, and voltage readings taken "on load," indicate trouble when all the cells in the same circuit do not agree. To prevent a false indication of this kind, care must always be exercised not to spill electrolyte when using the hydrometer, and especially to return all liquid taken up with that instrument to the cell from whence it came.

Meter Readings

Meters are the only method we have of looking inside of the wires and seeing what the electricity is doing. Many projectionists become so used to the meters in their system that they forget to watch them. But the trouble of watching all of them all of the time will be more than compensated by the troubles it saves.

Two Things to Ask Yourself

In the nature of things, this chapter cannot possibly mention all of the thousand steps of care and of precaution

needed for all the different sound systems in use. Taken together with the many details previously covered in connection with individual parts of the equipment, it tries to provide as many helpful hints as possible. Your own experience with your own system must do the rest. But you will seldom have the same trouble twice if you ask yourself, each time something happens, two questions:

1. What step of care or of precaution could I have taken that would have prevented this trouble?

2. What symptoms did this trouble show in advance, by which I could have detected it before it became serious?

In the light of the mechanical and electrical principles which have already been gone over, only a very unusual case should give you any difficulty in finding the answers to those two questions.

Ten Questions

1. How can drawing up routine forms help you care for your equipment?
2. How can you guard against microphonic tubes?
3. How can you guard against noisy B batteries?
4. What can happen if a rectifier transformer, or a bank of filter condensers, breaks down?
5. What warning sign do these often show in advance?
6. What damage can be caused by a tube that is internally short-circuited?
7. Why must tubes be matched for plate current in a full-wave rectifier?
8. What trouble can be caused by bad contact between tube and socket?
9. What damage can be caused by excessive current in the speaker field?
10. What two forms of bad treatment can shorten the life of a storage battery?

Ten Answers

1. By serving as reminders to see that nothing is forgotten in daily, weekly, and monthly inspections of the equipment.
2. By testing all tubes, before they are set aside as fit for use, in sockets where a microphonic tube can be troublesome. Compare each one with another tube known to be good. Flick the tube to be treated with your finger nail and pass it as satisfactory only if it makes no more noise than the standard tube.
3. By watching their voltage and by listening for noise in a headset connected across the terminals. This test should be applied more frequently as their voltage goes down with age.

4. Show stops. If the condensers break down first they may create a short circuit across the transformer secondary and cause that to follow.

5. Overheating; when tar is used for packing this may melt and ooze out.

6. Can draw excessive plate current, and so overload and burn out almost anything in the circuit.

7. Because in the case of a mismatch one tube will tend to carry an undue share of the load, possibly burning out its side of the power transformer.

8. Sound may stop when this happens with small tubes, where a bad contact may open the circuit, especially the grid circuit; with larger tubes arcing at the socket prong, ruining both socket and tube.

9. Can burn out field coil. Can overheat speech coil and so help that burn out. Can melt cement by which speech coil may be fastened to the diaphragm, allowing these two elements to come apart.

10. Introduction of foreign substances into its chemical system through lack of cleanliness or through refilling with other than pure distilled water. Overheating, especially by charging too long or at too high a rate of charge.

CHAPTER XIII

TRACING TROUBLE

The most important requirement in curing trouble in a theatre being to cure it quickly, you save time by doing most of the "trouble-shooting" in advance. In other words, you learn your system; the one, individual, collection of apparatus and wires that you handle daily. You can learn it in advance, or you can begin to study it during an emergency, but in either case you have to know it before you can find its failings.

Quite likely your installation is serviced by its manufacturer, and you may have seen your service engineer start to work on an emergency by taking out a book of blueprints. You can do the same. But the service engineer may be rushed on call to any of a large number of theatres, each with a different sound system. The projectionist who is responsible for one installation only can save a good deal of time by knowing as much as possible about its details.

Next in importance to knowing your system (and no one can be expected to know everything, even about one sound installation) is having necessary information where it can be found readily. Mention has been made before the diagrams which are often pasted up inside the amplifiers and other panels. If these are lost, or are too badly soiled to read, have them replaced. If at all possible—and it usually is—obtain from the manufacturer who installed your theatre a wiring diagram showing the connections between different parts of the equipment. If there is a junction box, such as is frequently furnished, with connection blocks that join many or most of the circuits in the system, that box is, or should be, "hooked up" according to a very definite scheme. Procure the code for it or the drawing

of it and paste this inside the cover. You will be repaid some day when a whistling audience waits while you find one certain pair of wires in that box.

But almost as valuable as knowing details or having detailed information easily available is having a very good general idea about the system, that is, knowing the electrical interrelations of every part. The advantage of this is obvious. But it is also obvious that such knowledge is useful only in proportion as it is thorough. You know your dry B batteries feed the photo-electric cell, but in

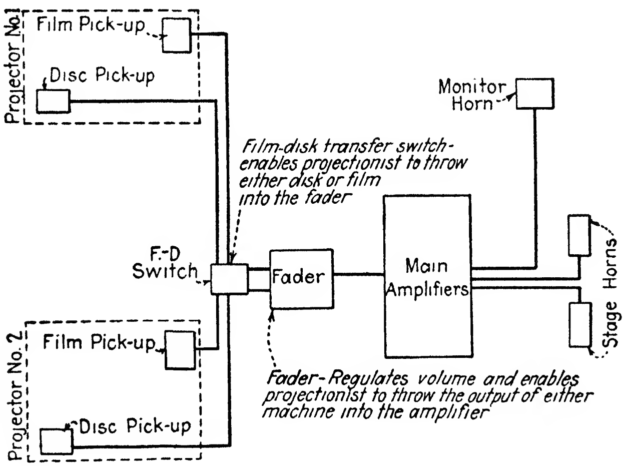


FIG. 81.—Block schematic of a generic sound installation, in which the different pieces of apparatus are represented by oblongs and each connecting line may be taken to indicate one pair of wires.

case of trouble in the line that is not enough. Just how do those wires run? Direct? Through a junction box? Through what switches? Where are they fused? Where can they be "picked up" to test for continuity? Where is a break most likely to happen? This is the sort of knowledge the man who finds trouble quickly and easily will have, and it is precisely the sort of knowledge no book can give him unless it is a book written especially about his own individual sound installation. It is the sort of thing he must, on the basis of a good and thorough general knowl-

edge of the theory of a sound system, find out for himself. And until he knows it, he will always hunt trouble the nervous way instead of the right way.

But it unquestionably remains for every man to decide for himself whether he wants to find these things out before or after trouble starts.

No Sound

"No sound" is usually the easiest thing to trace down. Your pick-up should be creating sound current; this should be passing through your system and being amplified; and

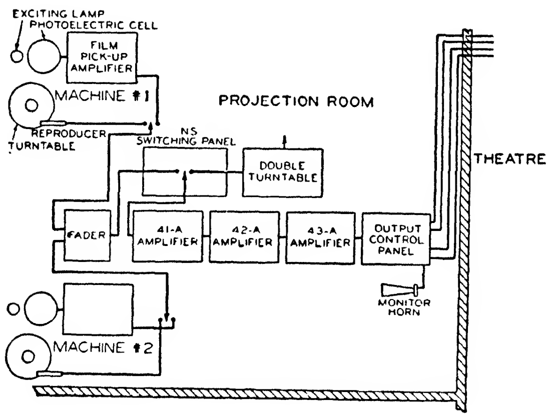


Fig. 82.—Block schematic of a typical Western Electric sound-system installation.

the speakers should be receiving it and converting it into air waves. Starting logically at the beginning, you want to know, in the first place, whether the pick-up is creating sound current at all. But you can kill two birds with one stone. You have another projector. Swing over for a moment and see if you can cause a click by interrupting the exciting lamp beam or by flipping the reproducer needle. If you can not you have automatically cleared, not only the pick-up on the machine that is causing the trouble, but everything else between it and the point (in most systems,

the fader output) where the leads from the two machines join to go to the main amplifier. If you *can* create sound from the other projector, you have cleared everything behind the point where the two projectors join, and then

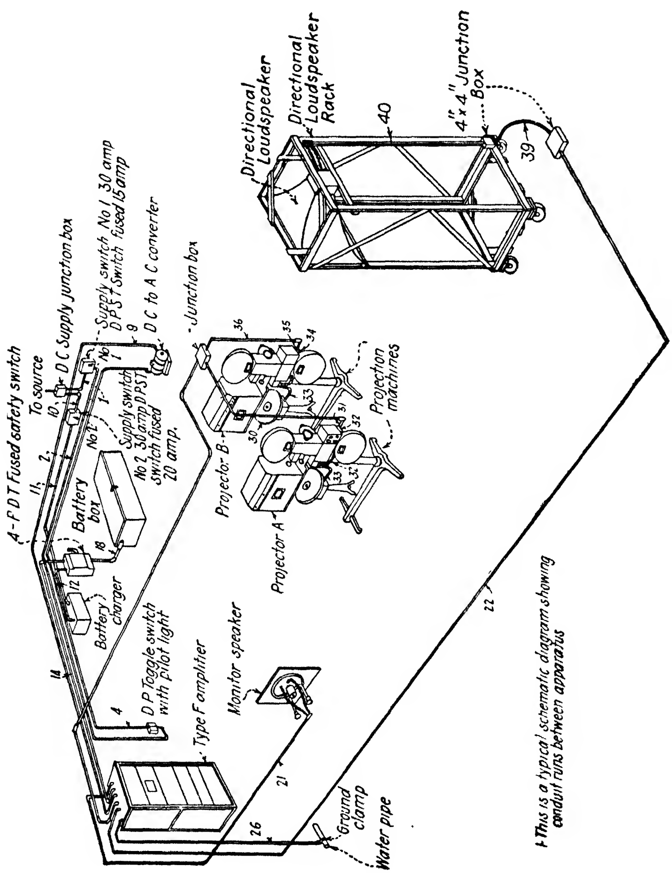


FIG. 83.—Sketch showing general layout and interrelation of parts in RCA-Photophone type PG-10 equipment.

you can well thread up on the good projector and give yourself 20 minutes more to trace the trouble without further interruption to the show.

But until you make such a test there is no use in threading up on the other machine; the main amplifier or the speaker circuits may be at fault.

The principle involved in this simple trick, which everyone will practice without advice, is the principle back of all quick and successful trouble-hunting of this kind. Split your system in half and see which end is at fault. Split that end in half again, and so on, until you have traced your difficulty to a very limited location, when you can either change the part at fault or examine it in detail, as circumstances may indicate.

Meters And Switches First

But before doing anything, before making any kind of test, it would be advisable to glance at all your meters, and (if the trouble comes in at a changeover) at all fader and synch-non-synch switches. If the trouble first appears at the beginning of the show, look at all switches. This should be done first of all because it takes the least possible time. It will take even less time if it is done systematically; in this case you do not start at the middle and work both ways, but logically at the beginning—at the pick-up—and work toward the end—the speakers. Starting at the middle does not save time here, because you are not looking for continuity. By working logically you will be saved the delay of looking at everything three times to make sure nothing has been overlooked. But, if more than one man is available at the moment, both may well start at the middle of the system and work out toward opposite ends. If it is done this way, examining every meter and switch in the equipment is a matter of seconds.

It takes much less time to do this than to describe it. The chances are your system is so arranged that you can read every necessary meter and see every switch by taking two steps. The exact routine to follow is again a matter to be determined by each man's own individual projection room, to be decided by himself and those working with him on the basis of common sense and saving time. Starting continuity tests in the middle of the system, on the other hand, is common sense for any installation of any kind.

Tracing Trouble

Assume that you have traced the cause of no sound as far as one projector. You next want to know if only the film, or both film and disc, is involved. If you were using disc, swing over to film, or vice versa, and apply a click test. If you hear sound, that clears the fader. If not, it clears the pick-up you were using.

Assume that the trouble is now localized in one film reproducing system. You have threaded up on the other projector, and have the rest of that reel during which to find and fix your trouble. Assume that the exciting lamp is burning and functioning properly and that whatever meters are connected with that end of your equipment give normal reading. You now want to know if the photo-electric-cell is working. But let us assume that this is one of those low-output cells that will not operate a headset but needs an amplifier mounted directly on the projector. So you can only prove that the cell is not working by proving that everything else is, or by replacing it with a cell known to be good. What is the quickest procedure for checking the rest of the equipment on that projector?

First connect the headset to the output of the amplifier. Here a knowledge of the details of your system saves time; you know just where to find that output. Listening at that point, you flip the first tube in the amplifier. (Your knowledge of details also tells you which is the first tube without the delay of looking this up, but, if you do not know, it is obviously the tube to which the photo-electric-cell lead connects. If you have not found out in advance which that is, you will have to take time to do it now.) When you flick that tube with a finger, you hear a ringing sound. It still remains to be seen if the system is clear from the amplifier to the fader. The fader has already been cleared by a click test on disc. Here you must know your switching arrangements thoroughly. If sound can get as far as the fader input with everything set for the other projector—which is running—you connect your headphones there.

If not, go as far past the photo-cell amplifier as is possible under the circumstances—to the other side of the attenutator, perhaps—and repeat this test of flicking the first tube and listening for the sound in the headset. Let us assume you clear everything as far as the fader, and that that and everything behind it has been cleared already. Then you have traced your difficulty to the photo-electric cell, in a matter of two minutes or so.

But photo-electric cells seldom fail to give some sound as long as they remain unbroken. Before changing the cell it will be best to check its B supply. To test that you need only a voltmeter and some more knowledge. A voltmeter reading right across the cell will not reveal anything. A very high resistance, perhaps a million ohms, will be in series with the cell, and no ordinary voltmeter will work on the tiny current which passes through that. So you must know where that resistance is, and take your reading on the battery side of it. Probably it is of the "grid leak" type. If your meter indicates, replace this resistor, and then the cell; the trouble can not be anywhere else. We have assumed that the exciting light is functioning normally, and have proved that the amplifier is operating properly from the first tube on.

Let us take a slightly different case—assume that you did not get the sound of flicking from that first tube of the photo-cell amplifier. Then there are many interesting possibilities, and you will be helped somewhat by experience. For example, there is one type of this amplifier on which the output transformer has some tendency to burn out. You have tested across the secondary of this transformer. Now repeat the test across the primary and see if sound has reached it. If it has, a new transformer is needed, and about all that can be done is to wait until it arrives.

A Good Rule

But then, again, no sound may be heard at the transformer primary. Here is another good general rule.

Before looking for trouble in an amplifier, or any similar piece of equipment, check the supply lines.

The photo-cell amplifier is supplied with A and B current. If the tubes light normally, the A supply is cleared. You will next check the B potential with your voltmeter to see if that is coming in.

Suppose it is not. Here again knowing your system helps you. Is there a fuse in the line? No book can tell you; you must know. Where is it? If there is none, where else can the break be? Is there a switch in the line? Do the wires go through any connection block? Is there any point along this feed you can check quickly with your voltmeter?

After fuses and switches, you will read the voltage at the battery. If a fuse is gone, check the voltage at the amplifier again after replacing it. Do not jump the fuse; there may be a short circuit somewhere that has blown it out.

Suppose there is such a short circuit. It may be in the film amplifier, or in the photo-cell or in the feeds. Is there any quick way of telling which is the case? The B circuit is through the vacuum of the tubes; you know that. Take the tubes out so that there can be no circuit through them, disconnect the B supply lines, and test with a battery and ammeter across the B circuit terminals. The negative terminal may be either one of the filament leads or ground; your drawing will tell you. If your test shows no continuity with the tubes removed, the short-circuit is in the supply lines and not in the amplifier. About the best thing that you could do for your show at that point would be put the B batteries on the floor next to the projector and wire them in direct. You can then take your time about finding and correcting the trouble.

If, on the other hand, the trouble is in the film amplifier itself, you will trace the B circuit in that amplifier, with the help of drawings.

These seemingly random examples of how to trace trouble have all been chosen with a definite idea of setting forth certain principles. Suppose we go over these.

Principles of Trouble Hunting

Check meters and switches first, doing it according to a system you have worked out previously to save time and make sure that the check is thorough. Test for continuity in the middle of the system, and then test in the middle of the half that shows the trouble, and so on, dividing each time till the difficulty is localized as far as is possible. To do this efficiently you must know, thoroughly, the interrelations of every part of your equipment.

When the trouble is localized, try again to split the possibilities into halves. As explained, if your B battery line is short-circuited, check at the amplifier to find out if it is in that or in the supply lines. (But in checking *inside* the amplifier you will probably find it best to take a drawing and start at the beginning and work through, unless you know that circuit very well.)

Moreover, in tracing the exact trouble after its approximate location is found, you must know the details of your equipment; you must know, for example, that a voltmeter simply will not read directly across most photo-cells because of the high resistance in series with the supply line. If you do not know these things you will waste much time hunting troubles that do not exist.

There is the story of the projectionist whose sound grew noisy when the rubber pad under his film amplifier had swollen with oil. He telephoned for a new pad, and meanwhile tried to swing the amplifier so it would hang straight again. He swung it as far as it would go, but it would not go far enough. There was a slot, and a bolt went through this into a tap in the iron plate behind. The bolt was intended to hold the adjustment. When the end of the slot reached the bolt that projectionist had done all he could do. Sound from that machine was very noisy all day. At last, the other shift came in, took the bolt out and moved it to a second tap further down, and swung

the amplifier clear. The first man did not know that there was another tap.

No one can know everything, but the more you can teach yourself about such small details of your system the less time or help you will need to clear up your difficulties.

Trouble in Amplifiers

There are four circuits in any amplifier; A, B, C,[1] and speech. These overlap; one current may share part of a circuit with another, but there are four distinct circuits none the less. Trouble can be located by tracing each one.

To save time and work, you study whatever indications there may be of which circuit is at fault. Meters may tell you immediately; at least they may tell you which circuits are good if not which one is bad. If the tubes light normally, the filament circuit is cleared. But if there is trouble in the filament circuit, it may be caused by a short circuit involving the high-voltage plate current. When there is evidence of this, further search should be made before the filament circuit is repaired. Continuity and short-circuit tests of the kind just mentioned in connection with the film amplifier save a great deal of time. If the amplifier under suspicion has a rectifier built into it, the B voltage can be checked across the rectifier output exactly as if the rectifier were in another panel. A voltmeter is used to test the A, B, and C supply; and headphones are used to check the speech circuit. Keep test buzzers away; they pass too much current and may damage any speech winding.

Low Sound

Low sound is a little harder to find than none at all. You can tell if there is some output or none from any given part of the equipment, but you can not always say whether the output you hear at any given point is of the proper volume.

[1] The C "current" is only a potential; no appreciable current flows.

Checking low sound therefore involves less physical testing and more mental analysis. What are some of the things that cause it?

A high resistance developing anywhere in the speech circuits is one. This again divides into two possibilities; the high resistance may be a switch or a fader contact, or perhaps a bit of dirt on the grid prong of some tube socket, or in some rheostat. The second possibility is that some definite piece of apparatus may have developed high resistance. A tube or a photo-cell is more likely to do this than any other part.

Low current supply is one obvious cause of low sound and this again divides into several groups; high resistance developing in a supply circuit, as, for example, a high resistance fuse or soldered connection corroding, or corroded contact to a battery. In the second group of causes, batteries may be low or a generator may not be delivering its rated output.

Likewise, those places where the sound is physical before it becomes electrical need consideration; the exciting light may be out of focus or the reproducer needle may be loose in its holder.

Checking for low sound involves much the same method of dividing the system and localizing the trouble previously mentioned, but this method cannot be carried out to the same lengths.

The simple physical causes may be checked first; they take the least time and are the most likely to be involved. If the difficulty is not found with them, the next step is to try both projectors, and both film and disc. If regular and emergency amplifiers exist, both should be tried of course, and the stage speakers may be checked against the monitor.

However, tracing circuits within an amplifier, or any similar procedure, is obviously not in order unless a volume indicating instrument is available. An easier step is to check for high resistance by changing tubes, etc., or to check the current supply by meter readings, whichever

happens to be easiest in your own installation. Since the probabilities of finding the trouble are about even, it is sensible to take the quickest method first.

In the film pick-up there are several physical conditions that can cause low volume, including bad focus, blackened exciting lamp, oil in the optical assembly, or sound aperture improperly inserted, so that it blocks off some of the light that should reach the cell. You can remember these merely by starting at the exciting lamp and running down the light for anything that might cause insufficient photo-electric cell illumination. At the disc end changing the reproducer is the quickest test.

Troubles That Appear Irregularly

Troubles that come and go are by far the hardest to find. Localizing them takes time, for one never knows whether the noise, or loss of sound, has not appeared on projector No. 2 because only No. 1 is involved or because it just happened not to show up while No. 2 was running. The same applies to distinguishing between film and disc.

Except as you can be guided by past experience and by obvious probabilities, troubles that come and go are primarily matters for reflection and analysis. You sit down with pencil and paper and list every cause you can think of for that particular trouble, in the light of your experience and your general knowledge of the functioning of sound systems. You write these down as they come to mind, so none will be overlooked. Then you write down all possible cures for each possible cause. Then you apply all of them at once and pray that the trouble will not return. If it does, you continue in the same way. There is not much testing that can be done, except for such checks as can be applied while the difficulty lasts. If it lasts for extended periods of time, including times before or after the show when all possible tests can be applied, that is another matter. Then it can be traced like any other difficulty; perhaps with a little waste of time due to periods when it does not exist. But these troubles that appear

only occasionally, and do not stay long, call for much thought and all possible adjustments applied at one time. There obviously is not a great deal of room for a process of elimination when you can never be certain whether your last change has eliminated the trouble or whether it chose that moment to eliminate itself.

The worst of all troubles of this class is an intermittent pick-up of outside interference, the kind that appears as a hum in the sound. Outside pick-ups are always unpleasant to deal with, but when they are complicated by irregular occurrence they constitute about the worst enemy possible to any sound installation. More will have to be said about this in considering the causes and cures for noisy sound.

Noise

Foreign noise in the sound provides at once the most common and the most difficult group of troubles. So common that there is always some present, whether or not it is too little to be of any importance. Its causes are almost innumerable. The indispensable first step in dealing with it is to classify it.

Let this be made clearer; in dealing with loss of sound we eliminate different parts of the equipment in the most efficient way possible, until the trouble has been localized. In dealing with foreign noises the first step is to eliminate all but a comparatively few possible causes for the trouble by classifying it as a definite kind of noise.

Noise as Distinct from Hums

Pure noise, not a hum, is a definite thing. It has a number of causes, and these can often be named by listening to the character of the noise. Pick-up of the projector vibration is not likely to be confused with any other sound that comes out of your speakers. It is distinctive; in bad cases the projectors are heard through the speakers; in cases less severe, remnants, disembodied ghosts, so to

speak, of the sound of the projectors are heard. These remnants are not hard to recognize because they have a distinct sound of their own. If your experience has not been sufficient to help you to recognize them, you can improve it by a simple trick—install microphonic tubes in the photo-cell amplifier and run your machine without film and with the volume high. Start and stop the projector motor. Bring the volume up and down with the projector running. Starting and stopping the motor will definitely identify what you hear with machine vibration; raising the volume will bring the noise in more strongly; lowering the volume will show how projector vibration pick-up sounds when only a little of it is coming through.

The cure is to find and eliminate the cause of the pick-up. This has been gone over before. It may be improper focus or a loose exciting-lamp holder; loose slits or lenses in the optical assembly; a loose element in the photo-cell; a microphonic tube in the film amplifier; or a defect in the spring suspension of that amplifier which allows it to touch its casing.

A microphonic tube in the main—as well as the photo-cell—amplifier can create noise in the system, but this noise will not commonly sound like projector vibration; it will not sound like anything in particular and when you hear such a noise you may suspect a microphonic tube in the system amplifier.

Storage batteries that are run down are often noisy; their characteristic sound is an irregular crackle, complicated by a hiss. The same is true of low B batteries. A defective fuse in either of these circuits may set up a very similar disturbance.

Another source of irregular crackle—with or without any hissing component—is a loose connection anywhere. This may be in the fader or at some switch in the sound circuit; it may be dirt in a socket, or it may be a resin or acid soldered connection anywhere, or a bad fuse in some supply line, or dirt in any rheostat.

Hums

Hums are distinct from noises in that they have a definite frequency, or tone. If there is a fair-sized power transformer in your system, you can hear a 60-cycle hum (assuming your line is 60 cycles) by putting your ear reasonably close to this transformer. (Do not touch it.) Sometimes that hum comes out of the speakers as a pronounced "system noise." Then the core of the transformer may be loose and vibrating. Often the plates composing this core are held together by nuts and bolts; tightening these will cure such system noise.

Hums of other tones can be due to almost any number of causes; their pitch, or frequency, is the greatest single help in tracing them. If your system uses a 720-cycle alternator as part of its speed control a hum of that frequency may sometimes be heard through the speakers. Better grounding of the control box, used with such alternators, and of the projector base is one remedy. Commutator hum from your driving motor, regardless of its type (if it has a commutator at all) is not infrequently picked up; this sound can readily be identified by comparing it with the physical sound of the motor in operation.

If the photo-electric cell is exposed to light from any alternating current lamp—as may happen if the door of its compartment is left open—a hum of the same frequency as the light-current supply will appear in the sound.

More Noises

The photo-cell may produce a characteristic noise, a sound somewhat like the hiss of escaping steam. When this is serious the cell must be replaced. However, bad B batteries sometimes cause a similar effect, and should be checked with headphones before the photo-cell is discarded.

Surface noise on disc has rather a similar sound. In the chapter on Disc Mechanics the causes of this trouble were discussed thoroughly. In some systems a "surface" or "scratch" filter is used to eliminate this, and where the

filter is adjustable extreme needle scratch on disc reproduction can be controlled by it. However, this control must be used with caution, since the higher frequencies are filtered out together with the surface scratch, and the physical causes of excessive needle noise, previously discussed, should always be checked before the filter is touched.

Scratched or dirty sound track has its own characteristic noise, by which it can be recognized.

Noisy Pick-up

Arc lamps, and arc feed motors, often give rise to a "pick-up," creating noise in the system. The arc pick-up has a characteristic sound, the same "pst-pst" that is heard in the lamp house when the light is trimmed. When this sound issues from the speakers, better grounding of the projector base or sizeable condensers across the arc supply are indicated.

The automatic motors that feed the carbon in some lamp houses sometimes set up a clicking noise when their relay contacts are dirty or imperfect; and their commutator hum may be picked up when the brushes and commutators, for any reason, fail to make good contact. Repair of this equipment is one cure and connecting condensers across the poor connection is another.

Tracing Outside Hums

The hardest of all hums to deal with are those picked up from outside the system, which come in through the power lines or the ground connections. Commutator noise or other imperfect contact on power machinery almost anywhere in the neighborhood may, upon occasion, affect your system. If the source can be found the problem becomes one of persuading the owner of such equipment (unless it happens to be a ventilating or other motor in your own theatre) to correct his machine or to install a suitable filter.

Since electrical machinery does not always run 24 hours a day, tracing a source of outside pick-up is often made

easier by the trouble being somewhat irregular. Recording the exact times when it appears helps to identify the faulty equipment. Hums of this kind have been traced to many things—from faulty wiring of the theatre marquee to a Frigidaire in the apartment house next door. When the hum never stops a faulty insulator or some similar trouble in the power line may be the cause of it, and the power company can usually offer substantial help in running this down.

The Point of Pick-up

If the outside source cannot be found, the point of pick-up in the system must be located. Here the same process of elimination which has been gone over previously is the most helpful—except when the trouble is erratic, and then the problem is extremely difficult and calls for heroic measures. In most cases the process of elimination will promptly throw the blame on the film reproducing apparatus—especially when an amplifier is used with the photoelectric cell. Here the original sound current is very weak, while the amplification is greatest, and consequently an outside pick-up has every encouragement.

Grounds

Wherever electric charges at different potential exist, and are connected by any conductor, current will flow. Such charges may be created in a conductor by inductive or capacitative pick-up. If every part of the system casings and conduit are well grounded, they will all be at the same potential—theoretically. Actually, perfect grounding is impossible, and since the amplification in sound systems is quite high, small ground-circuit currents can cause much trouble. Sometimes improving the ground helps. Sometimes it is found more helpful to remove a ground connection. Logical analysis and procedure are still largely wanting here, and after the point of pick-up has been localized, intelligent effort must often be supplemented, in these cases, by the old method of trial and error.

Distorted Sound

Distorted sound may be due to many things in the system. Its cause is localized by the process of elimination; it is not always possible to go further than this under projection room conditions, and the commonest remedy is to replace the amplifier or other part that is proven responsible. Of course, such things as a defective needle or poor exciting focus, or incorrect current supply to the various tubes, to the speakers, or to the exciting lamp, may be responsible, and these are simply adjusted.

Distorted sound is very often due to acoustic rather than to electrical conditions, and acoustics constitute one more step of elimination which must be applied in this particular case. Listening by placing one's ear very close to the speakers is one test, but not a perfect one. Listening to the monitor, with stage speech turned off, may be used to check upon it, for extremely bad acoustics have been known to spoil the quality of sound in the air very close to the stage speakers.

Soldered Connections

Soldered connections should have a word here, since they are important in much repair work. It is unfortunate that a great deal of experience at soldering power lines or radio receivers does not always mean skill in soldering sound systems' connections. The reason is simple.

A soldered connection involves an intimate union between two metals, and for this to be achieved the surface of each must be chemically clean. To secure such extreme cleanliness a "flux" is used, which removes slight traces of oxidation and other impurities from the surfaces. The flux may be an acid; it is often resin.

Acid is not suitable for use around sound systems. With time, it is liable to give rise to a chemical action resulting in corrosion of the metal, and so increase the resistance of the connection. In power work this would be relatively unimportant. The voltage and current involved are nearly

always too great to suffer much from a slight change in resistance. In sound work, and especially in speech circuits, both voltage and current may be so low that a little corrosion becomes a very serious thing. Therefore the common practice is to use resin for a flux. This is often applied as the core of a hollow wire of solder.

Resin soldering has its own drawback. Since resin is a non-conductor, it must be thoroughly boiled out of the connection. When it is not, it not only causes an imperfect contact, it often prevents a soldered contact being made at all. Resin hardens when the heat is removed, and has sufficient strength to hold the two surfaces together as if they had been properly joined, while the solder about it may hide the fault from the eye. Only sufficient heating of the two surfaces will insure that a real connection is made. When there is any doubt, always tug at the wire or try to pry the lump of solder off with a knife.

Whatever flux is used, no connection is properly made unless the metals to be joined are hot enough to melt the solder and make it run freely. Radio soldering does not show this, because commonly the wire and lugs used in radios are so small that they heat to the proper temperature at a touch of the iron. The more substantial equipment used in sound systems does not always do this.

In soldering any connection in a sound system, use resin for a flux, and do *not* melt the solder with iron or torch. Heat the surfaces to be joined and let *them* melt the solder. This simple method will always insure a proper connection.

There is one exception to the rule of letting the metal which is to be joined melt the solder. A binding post to a transformer or condenser may refuse to become sufficiently hot. It is connected either to a great deal of wire or to a great many condenser plates, and heat may radiate through these as fast as it is applied.

Attempting to overcome this radiation by prolonged heating is not a good idea. The fine wire of the transformer may burn out, or the insulation in some types of condensers may be damaged. Where possible, heat such

a binding post thoroughly and very quickly with a large iron. If this cannot be done, remove the wire, solder it to a lug, and make a good physical connection between the lug and the binding post; but a sufficiently large soldering copper is usually all that is necessary for any binding post found in a sound system.

In addition, you will do well not to wrap the wire to be soldered around any lug or binding post. Hold it or have someone hold it there for you, and let the solder be the only physical bond. When the joint is cool, try to pull the wire off. Pull hard for if it comes off the connection was not good. This test *guarantees* proper results.[1]

Review

Since there are so many troubles of so many different kinds, going over the more important ones briefly may help to fix them in mind.

No Sound

No sound is run down by process of elimination, generally starting at the middle of the system and successively dividing the possible areas of guilt until detailed inspection of one piece of equipment is indicated. This itself may be subdivided and the trouble in it localized in similar fashion; or it may be replaced.

Low Sound

Low sound is somewhat harder to find, and after it has been localized as far as possible, the proper step may be analysis of all possible causes, and successive replacement of all possibly faulty parts, until the trouble is cured.

[1] This method of soldering takes more time—because it is more troublesome—than that in which the wire is physically fastened to the binding post before solder is applied. In quantity production work, as in factories or in telephone practice, the method recommended here is not followed. It is not needed in such work, which is done by skilled men who do nothing else, and it is more expensive because it takes more time. The projectionist who has other responsibilities, and who therefore handles a soldering iron only rarely, will be well advised not to try to follow quantity-production methods.

Erratic Troubles

Erratic troubles, or the kind that come and go, very largely defy analysis or logical procedure, and often call for heroic measures of listing and applying all imaginable remedies to all conceivable causes.

Noises

Noises have many different causes, and first aid in determining the cause of one is to recognize its characteristic sound.

The commoner causes of noise are pick-up of projector mechanism vibration, microphonic tubes, low or otherwise noisy batteries, irregular pick-ups (for example, from the arc lamp or the arc carbon feed motors or their relay contacts) and bad connections.

Bad Contact

Bad contact may exist in a switch, in a fader of any kind, in a "gain control," or in socket contact, especially a grid contact; or may be found in a defective fuse, or a corroded or resin connection. It may be in a rheostat or any other variable connection. Bad contact to a battery may be due to corrosion.

Hums

Hums are of many kinds, and can often be identified by their characteristic frequency. A hum may be due to a mechanical defect, such as sprocket-hole and dividing-line noise, or may be due to the pick-up from an imperfect commutator. This last may be in the projector motor, in the little automatic arc feed motor, in the generator that supplies any portion of the system with current, or in a totally unrelated motor that is anywhere near a sensitive part of the system, that is supplied by the same power line or that has a ground in the same neighborhood.

A hum at the frequency of the alternating current supply may be due to loose laminations in one of the power transformers. It may originate in the battery charger or

in any other equipment supplied by the same line, whether a part of the sound system or not. It may originate in machinery altogether external to the theatre.

When the source of the hum is located, a condenser filter, connected across the disturbing contact, is one remedy. Improving that contact till it no longer gives trouble is naturally preferable. However, it is not possible in every case.

If the source of the hum is outside the system and cannot be found, the point where the system picks it up must be located and the pick-up eliminated by improving the ground connection, or (sometimes) by removing a ground connection.

Radio Pick-up

Theatres located near powerful broadcasting stations have been known to pick up and amplify radio programs. In this case the sound system acts like an ordinary radio with phonograph attachment, except that there is, in addition, a sound-on-film attachment which is especially likely to cause the trouble because of its high amplification.

The remedy is to locate that portion of the system which is acting as the tuning end of the radio receiver and detune the disturbance by addition of condensers or coils of wire. Battery leads or the conduit that carries them are most likely to be the offenders, especially those connecting to the beginning of the train of amplification. Put condensers across the battery lines, and wrap 50 or 100 turns of wire around the suspected conduits—one end connected to the pipe and the other end free—until you notice either an increase or a decrease in the volume of the radio pick-up. Then you will have the right circuit, or one of them (there may be several). Further experiment will reveal the size of capacitance or number of turns of wire needed to tune out the offender completely.

The remedies here given are those most often found effective, but each case of radio pick-up is an individual problem and must be treated as such.

Speed Control Troubles and Acoustic Troubles

Speed control troubles and acoustic troubles are covered in the chapters dealing with those subjects.

Soldering

Soldered contacts in a sound system should always be made with resin for flux, and by heating the metal to be joined and letting that, rather than the iron or torch, melt the solder. An iron or torch sufficiently large for the work to be done should be used, rather than prolonged heating with an inadequate source of heat.

Confidence and Methodical Approach

Most important in tracing and curing trouble is the confidence that comes from knowledge, and orderly, efficient procedure. After all, as said at the beginning of this chapter, there are only two ways to attack any difficulty—the nervous way and the right way.

The whole aim of this book has been to convey a little more knowledge of the principles, and, wherever possible, of the details, of the workings of a sound system. It was unfortunately necessary in the nature of things to leave a great deal of the detail concerning individual systems to the individual reader. No book, except an encyclopedia of many volumes, could describe all the more minute details of all the sound systems that are in use. These must be left to the individual reader, and his success in fighting trouble will be directly proportional to his success in mastering them.

Ten Questions

1. Describe a practical way of applying the process of elimination to tracing trouble.
2. What different form of the process of elimination is applied to hunting out and curing foreign noises in the sound?
3. What, in addition to the process of elimination, may be needed in dealing with low sound? When and why?
4. What is the procedure for curing irregular troubles—those that come and go? When is this procedure applied?
5. What is essential to a good soldered connection?

6. What are three possible causes for a hum in the sound at the frequency of the supply line, and the cure for each?

7. What is the most probable cause of a hum in the sound at some higher frequency, and what are two possible cures?

8. What is the most probable cause of an irregular, crackling noise in the sound, and how would you trace this?

9. What would be the most probable cause of a noise that does not sound like anything in particular?

10. What two things can be done about foreign hums or noises which are apparently being picked up through the ground circuit?

Ten Answers

1. Starting at the middle of the system, or of the circuit which you think is faulty, divide this into two halves. Divide the half that is found to contain the trouble again, and so on, until the search has been narrowed to a very small area.

2. Classifying the noise as to cause by its characteristic sound.

3. Listing and investigating all possible causes, and all possible cures for each, whenever it is not possible to tell whether the output from some one piece of equipment is normal or not.

4. The same as in answer 3, when the trouble does not remain long enough for orderly investigation, and when the more obvious steps, and those based on past experience, do not yield results.

5. Heating the metals to be joined hot enough to melt solder.

6. (*a*) Loose laminations in a power transformer in a rectifier; tighten them, or, if the construction of the transformer does not allow this, replace it. (*b*) Defective contact or ground in some piece of machinery supplied from the same circuit, or grounded in the same vicinity, as your sound system. Locate and correct the trouble and install a condenser filter across it. Where this cannot be done locate the point of pick-up by the system and install a filter there, or improve or remove a ground. Or a similar trouble may exist in the power line, for example, a leaky insulator. The power company will help locate this; if it fails, the point of pick-up by the system must be found and treated as above. (*c*) Light from an alternating current source striking the photo-electric cell.

7. Defective commutator contact in some motor supplied from the same line, or grounded near the sound system ground, or working near a sensitive sound circuit. The projector drive and arc feed motors are often the cause of hums. (*a*) Cure the bad contact or place a condenser filter across it. (*b*) Where this cannot be done locate the point of pick-up into the system by the usual process of elimination and procede as in answer 6, (*b*).

8. Loose contact. Process of elimination, helped, if necessary, by detailed inspection for dirt, loose or corroded soldered connections, high resistance fuses, improperly fitting sliding contacts, as in rheostats, and other possible causes in the region the process of elimination indicates.

9. A microphonic tube in the main amplifier.

10. Improve the grounds. Remove them.

CHAPTER XIV

RECORDING

The manner in which sound is recorded seems to be largely mysterious to theatre folk; and still some knowledge of recording processes is necessary to a really complete understanding of the equipment in a theatre. To say that a needle picks up the sound engraved on a record tells only half the story; the other half is concerned with how the sound ever came to be engraved on the record.

A very brief description of the apparatus for disc and film recording, and a general outline of the work of a sound studio, may have some interest for the theatrical reader.

The Disc Recorder

Assuming your theatre has an announcing microphone, its equipment may be taken to represent a recording installation, with the loud speaker standing for the disc recorder. In another place the action of the speaker diaphragm has been described by saying that the diaphragm moves forward and back, forward and back. But if you stand facing the edge of the diaphragm, instead of the front of it, it is just as accurate to say that the diaphragm moves from side to side.

The disc recording device is in principle the same as a loud speaker, only it is equipped with a cutting tool, instead of a diaphragm. The wedge-shaped point of this tool, the stylus, is lowered into contact with a disc of soft wax. The disc is rotated under the stylus, and the stylus consequently cuts into the wax. When the recorder is actuated by sound currents, the stylus moves from side to side for the same reason that a loud-speaker diaphragm does, and the cut it makes in the wax will consequently waver from side to side. We have seen that the action of a loud speaker will faithfully represent the sounds entering the announcing

microphone, and we know the reason why this is so. For the same reason the action of the stylus of the recording machine faithfully represents sounds entering the recording microphone.

The wax turns under the stylus at a constant speed. Therefore if the sound being recorded is pitched high, and its vibrations follow one another quickly, the waverings

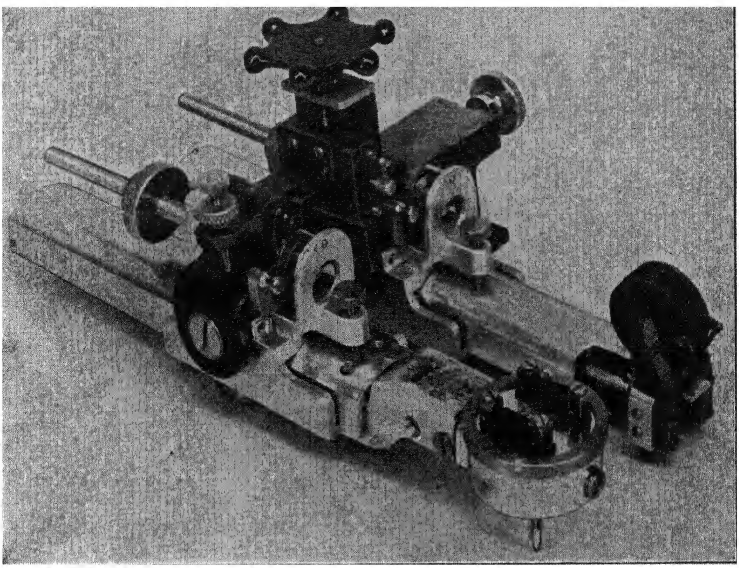


FIG. 84.—Western Electric recording stylus (rear) and "playback reproducer" (front) mounted on one arm to permit use of either.

in the line cut by the stylus will follow one another quickly. If the sound is loud, the stylus will move through a greater distance, exactly as the diaphragm of a speaker will, and the waverings in the line it cuts will consequently swing over a greater distance from side to side.

But, in your projection room the needle follows a continuous groove in the record, follows through from one end of the record to the other. There is no groove in the fresh wax; therefore, in order to create one the stylus is moved across the record by a worm gear.

Designing this worm gear motion required much thought. It is this that governs the spacing of the grooves (the thickness of the walls between grooves) and, consequently, the probability of a record breaking down in use. Twenty

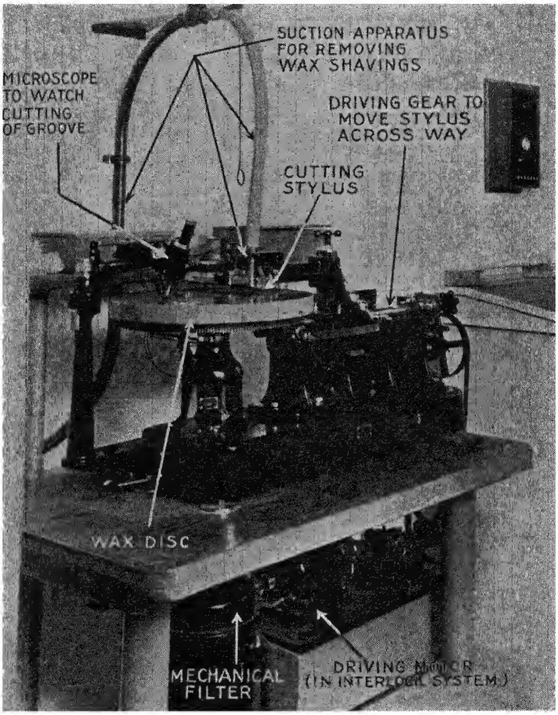


Fig. 85.—Western Electric disc recorder, seen from above.

minutes of sound has to be crowded into one disc; at the same time enough space has to be left for the widest swing of the groove necessary to record full volume. The grooves also must be shallow, for a thin wall can not be made very high. "Retakes" at lowered volume were often necessary in the early days of sound because the stylus swung too far.

The Recording Disc

The disc on which the recording is made is of beeswax, the finest and smoothest grain obtainable. The wax is

saved; all of the shavings are sucked away from under the stylus by an apparatus resembling a vacuum cleaner. The nozzle of the vacuum pump is mounted very close to the

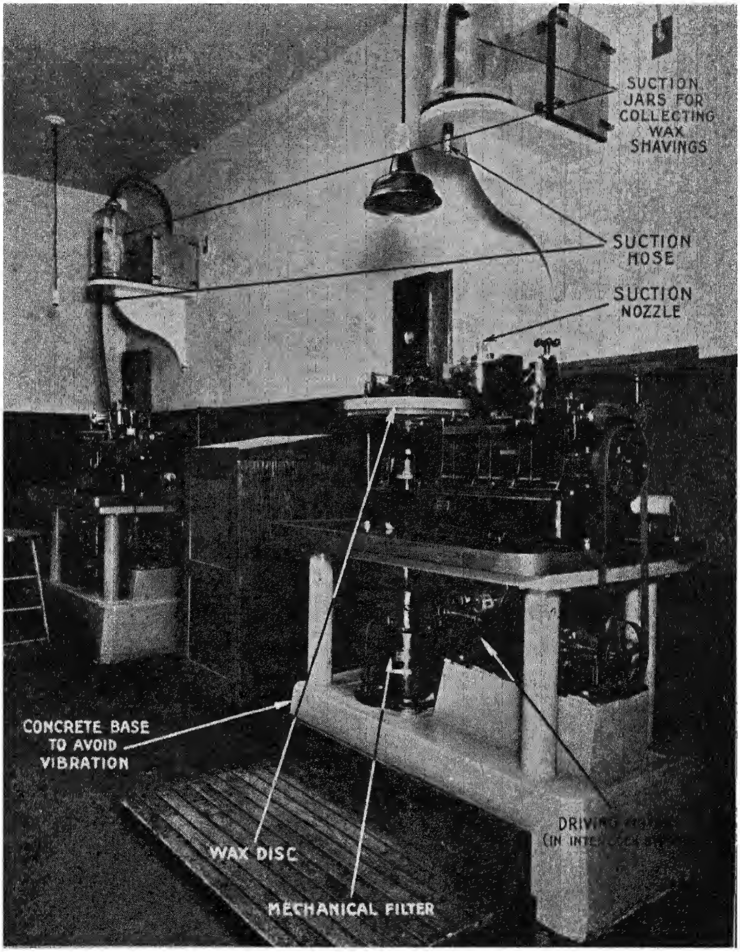


Fig. 86.—Western Electric disc recorders, showing driving system.

point of the stylus, and draws up the surplus wax in long gray strips that collect in a glass jar overhead. Wax, old and new, which has been boiled down, is cast into a disc more than 2 inches thick. It is then put on a lathe and the surface smoothed carefully. This takes a long

time, but is necessary in order that not the smallest irregularity may meet the stylus. The final smoothing of the surface is done with a semiprecious stone, since the best steel is not trusted to take a sufficiently accurate edge.

Two disc records are made simultaneously. The recording engineer watches the cutting with a microscope, and saves time by stopping the recording at once, if the stylus swings too far. When the recording is over, one record is played back. A special "playback reproducer" takes the place of the stylus. This also is driven across the record by the worm gear, as the soft wax could not move even the lightest reproducer. If the playback, which is heard through an amplifier by the director and all his cast, is approved, the other disc is kept for a master, from which records are made; otherwise the "take" is repeated.

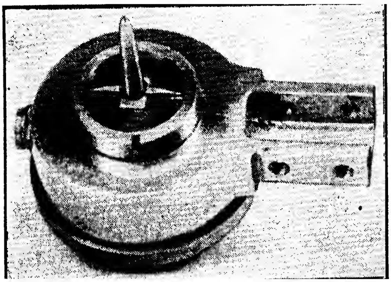


FIG. 87.—Detail of playback reproducer.

The master is carefully dusted with carbon dust, and placed in an electroplate bath. A metallic film is thus deposited on the master, a metal plate being formed which retains every shade of the waverings of the groove. When the wax and carbon dust are washed away from this metal plate, it constitutes a "negative" with which any number of "positive" records may be stamped.[1]

The disc which was used for playback is melted down. It is sufficiently damaged in the process to be useless as a master; a few playbacks make a soft wax record almost unintelligible.

THE FILM RECORDER

The Western Electric film recorder consists of a light-proof machine, carrying an upper and lower magazine,

[1] This condensed account covers only the fundamental principles involved; the actual process of making records from soft wax includes several intermediate steps.

in which a reel of film passes by a light aperture. An exciting lamp of the ordinary theatre type illuminates

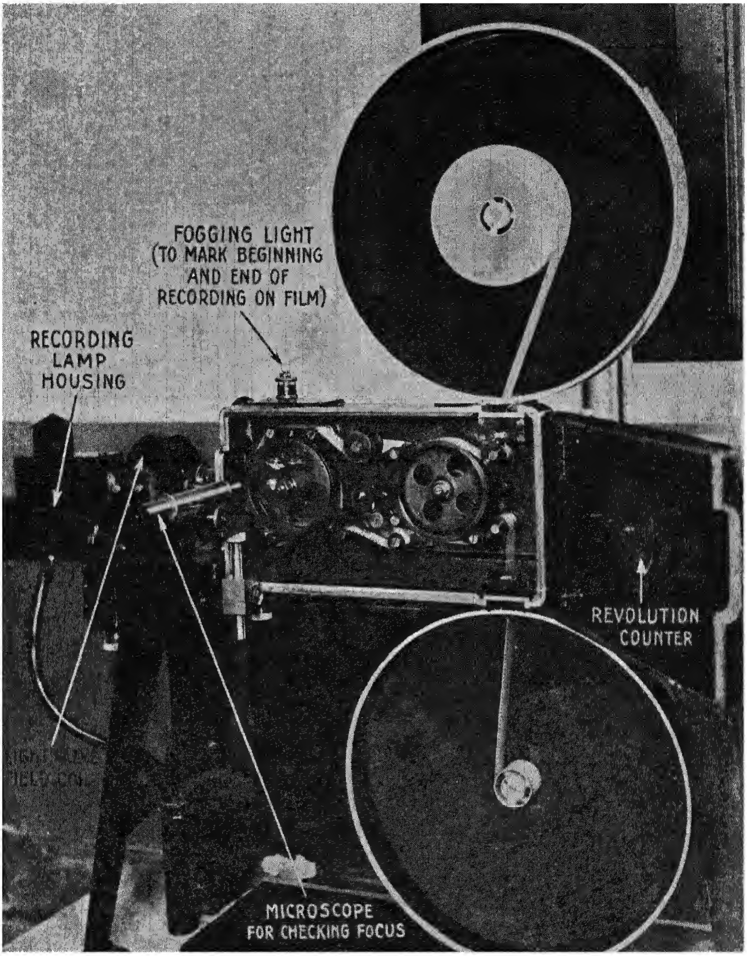


FIG. 88.—Sound-on-film recorder showing course of film.

this aperture. Between the light and the aperture is the "valve."

The valve consists of a slit, 2 or 3 mils high, and as wide as a sound track. In front of this slit there are two parallel metal ribbons, under tension. Speech currents

pass in through one ribbon, around a loop, and out through the other. The ribbons are weaker than a spider's web,

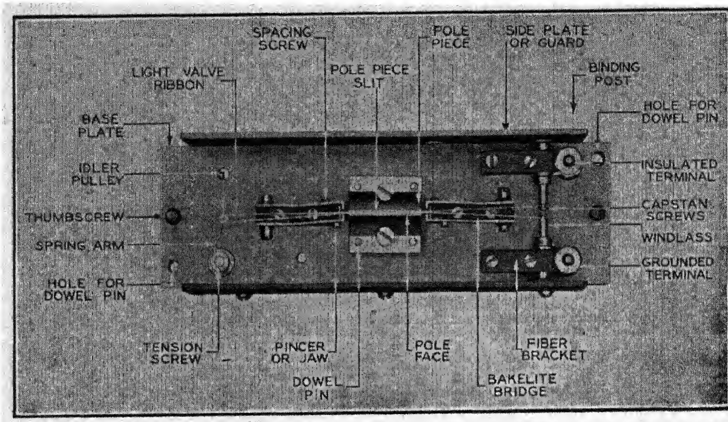


FIG. 89.—Western Electric light valve for recording variable-density sound track

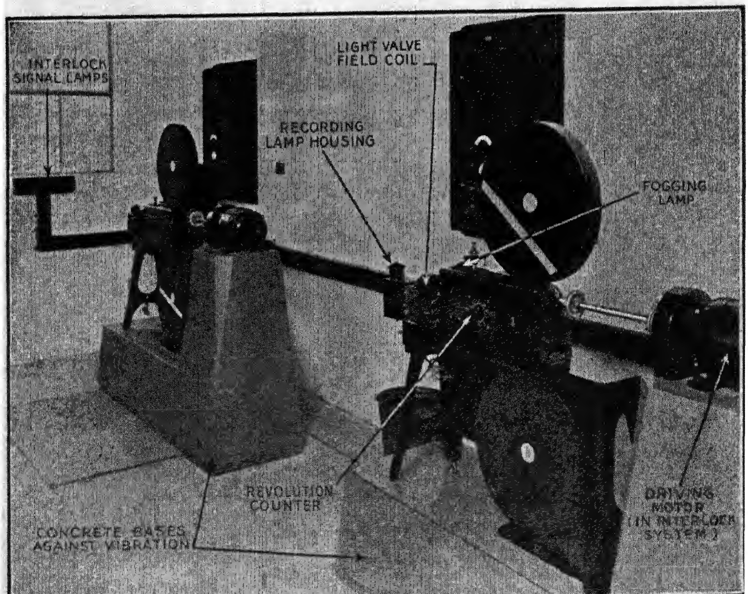


FIG. 90.—Western Electric sound-on-film recorders.

and thinner. They are in a strong magnetic field, provided by an inductive winding supplied with direct current.

These metal ribbons are so mounted as to be spaced about 2 mils apart,[1] normally. When alternating speech currents pass through them, they are either pulled further apart, or driven closer together, by the magnetic interaction between the flux of the permanent field, and the changing flux created by the alternating speech currents. The light that strikes the film is forced to shine in through the space between the ribbons. Aside from this the whole arrangement is light-proof.

Two "lens assemblies," similar in principle to the type used in theatres, complete the equipment, focusing the light first on the space between the ribbons, and then on the

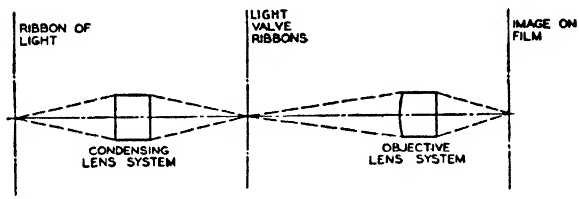


FIG. 91.—Schematic representation of light path in Western Electric film-recording systems.

film. The film is moving at a constant rate. The width of the lines photographed on the film as it moves past the light will depend on how long the ribbons stay open, and, conversely, on how long they stay closed. The intensity of the lines which are photographed will depend on how wide they open and how close they shut. The frequency with which the ribbons move, of course, will depend on the frequency of the speech currents flowing through them, while the extent to which they open or close, around their central spacing of 2 mils, will vary with the strength of those currents.

This arrangement includes provision for "direct monitoring." The film is transparent, and the light that shines upon it passes through it, and into a photo-cell placed just behind. This cell is similar to those used in theatres, but smaller in construction, as the more crowded space demands.

[1] More recently, $1\frac{1}{2}$ mils. But see pp. 244 and 245.

The output of this cell is amplified in the usual way, and allows all interested to hear exactly what is being photographed on the film. However, playback after "shooting" is impossible until the sound track is developed; and a disc record is often made simultaneously for that purpose.

Noiseless Recording

The recently developed "noiseless recording" is achieved by passing a "bias" current through the valve ribbons, in

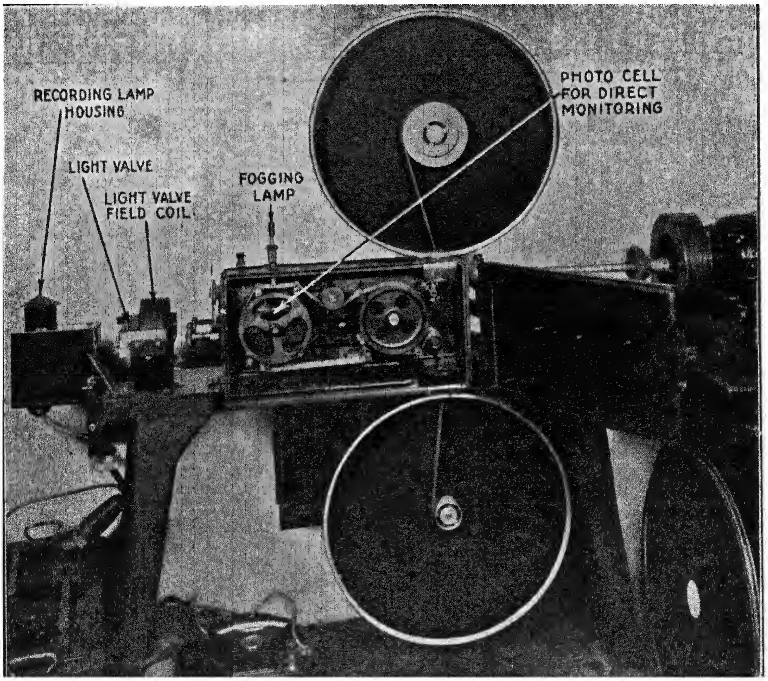


Fig. 92.—Sound-on-film recorder showing light valve in place.

addition to the usual speech current. The effect of the bias is to eliminate the former spacing of 2, or 1½ mils, and to keep the ribbons always closed when no speech current is passing. The introduction of speech current opens the ribbons, the average width of the opening depending on the volume of the speech current at any given moment.

In consequence, the positive print is opaque at all silent places, and at no time passes more light to the photo-cell than just enough to reproduce the volume at that moment. Therefore no film noise or photo-electric-cell hiss is created during silent sequences, while any that may be set up in the course of reproduction of sound are always so much lower in volume than the sound reproduced that they can never be heard.

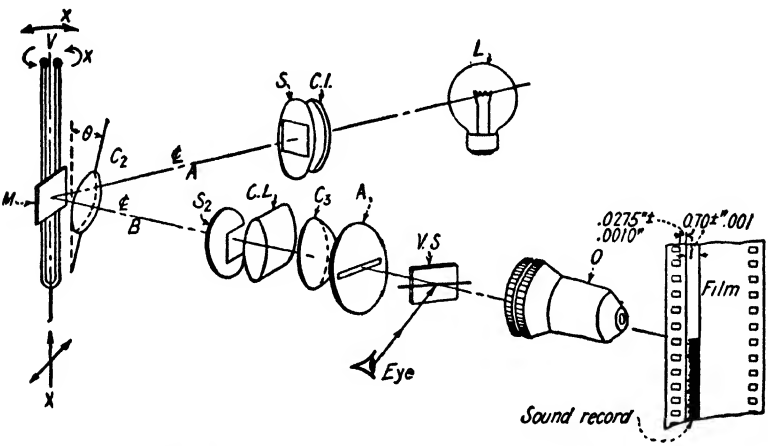


FIG. 93.—Drawing showing action of RCA-Photophone recording galvanometer and its associated optical system, for recording constant density, variable-amplitude sound track.

CONSTANT DENSITY METHOD

The R. C. A. type of sound track is recorded with a different device—a mirror galvanometer. Here the speech currents cause a small shaft to rotate, that is, not to turn completely around, but to swivel to and fro against tension. The degree to which it swings each time corresponds to the variations in the strength of the sound currents that move it, and the rapidity with which one swing follows another, of course, is governed by the frequency of those currents. A tiny mirror is mounted on this hair-like shaft, and reflects a very thin beam of light onto the film. The beam swings across the sound track from side to side, throwing light across a greater or lesser width of the track. Since the film

is moving continuously, the effect photographed is that of peaks of illumination, the height of which corresponds to the intensity of the recorded sound—the extent of shaft rotation achieved—while the frequency of the sound is represented by the frequency with which these peaks follow one another—by their spacing.

In the R. C. A. method of noiseless recording the swing of the light beam is so governed that only so much of the

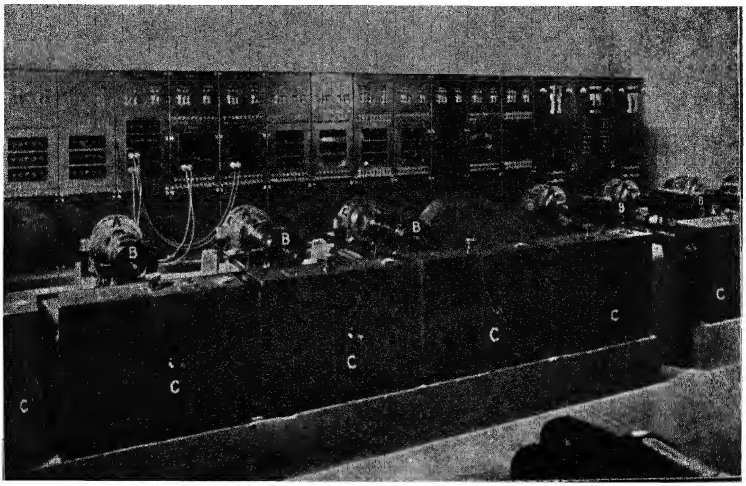


FIG. 94.—Motor room, showing row of distributors (generators) driven by regulated motors whose speed is controlled by the row of Western Electric 700-A control cabinets, seen in the foreground (one of each per channel). Behind the motors is the switchboard which allows any distributor not in use at the moment to be "patched over" to supply some other channel. *A*, interlock alternating-current distributor (generator); *B*, direct-current drive motors, controlled in speed by *C*, 700A control cabinets.

sound track is illuminated at any given moment as is necessary to accommodate the length of the saw-tooth indentations then being recorded. The remaining width of the sound track appears on the positive print as opaque.

THE INTERLOCK

But somewhere off in the distance is a camera taking a picture—just a trifle, the picture, often forgotten in these days of sound. Now the strip of film that represents all the sound of a "take" must be exactly as long as the strip

that carries the pictures corresponding; for later these two must be joined. The same considerations apply to the disc; it must turn exactly 33⅓ revolutions while the camera is exposing 90 feet of film. The starting points are of no enormous importance, for they can be set later in the cutting room, but the synchronism must be right. Therefore all the motors driving the disc recorders, the film recorders, and the half dozen or more cameras must revolve together. To secure this, they are all synchronous motors, that is, they are motors that will rotate in time with a given frequency. The alternating current driving these motors is generated in the studio; and every motor on a given "take" is supplied by, or "interlocked with," the same generator.

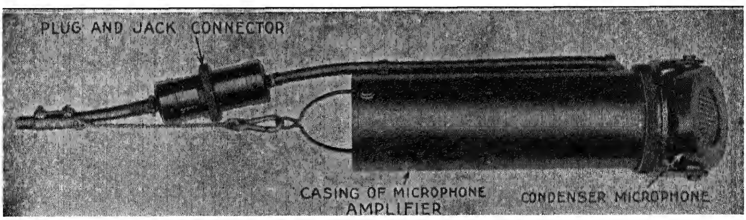


Fig. 95.—Recording microphone. (Western Electric condenser transmitter.)

But synchronism is not the only requirement. The speed must be accurately maintained, for the same reason that the speed of any theatre's projection motors must be right—to keep the pitch, or keynote. Therefore the interlock generator is driven by a motor similar to the one used in theatres, and equipped with a similar speed control device. A very accurate timer is shafted to this motor, and carefully watched.

The Microphone

The microphone which is generally used in recording is more sensitive and faithful in reproduction than the carbon button microphone that is used in theatres for announcing. It is a "condenser transmitter," consisting essentially of two discs of metal, separated by a very small air space.

The disc facing the source of sound is mounted in such a way that it is free to vibrate with any air vibration reaching it. It has no natural frequency within the limits of audible sound. When this disc vibrates with the alternate compression and rarefaction of sound waves, the spacing between itself and its brother disc is slightly modified. The capacitance of this condenser therefore varies with the change in spacing between the plates, and consequently the charge it will take alters. The extent of all these variations, of course, corresponds to the intensity, or loudness, of the sound waves that cause them, and their frequency to the frequency of those waves. The changes in the charge of the condenser microphone are used to "swing" the charge on the grid of a vacuum tube, and so to create speech currents.

The condenser transmitter is in a class with the photocell, in regard to low output. Its output cannot be led anywhere. Accordingly, a small amplifier is built right into the same casing. The whole looks somewhat like a 3-inch artillery shell, except that the point is replaced by the blunt face of the microphone, which is mounted to the casing on a swivel, so that it can be adjusted to pick up sounds from more than one angle without the necessity of moving the whole case.

Sound Stages

A large studio may have as many as a dozen sound stages, with the same number of "channels." A channel is a complete recording system—from microphone through the necessary amplifiers to the recording machines, including a separate interlock.

The stages for a number of channels are usually grouped in one building. Another building may hold all of the amplifier rooms; a third, the interlock rooms; a fourth, the recording rooms; and a fifth, battery rooms and whatnot. Any combination of these arrangements may exist, and the recorder is often a long way from the stage.

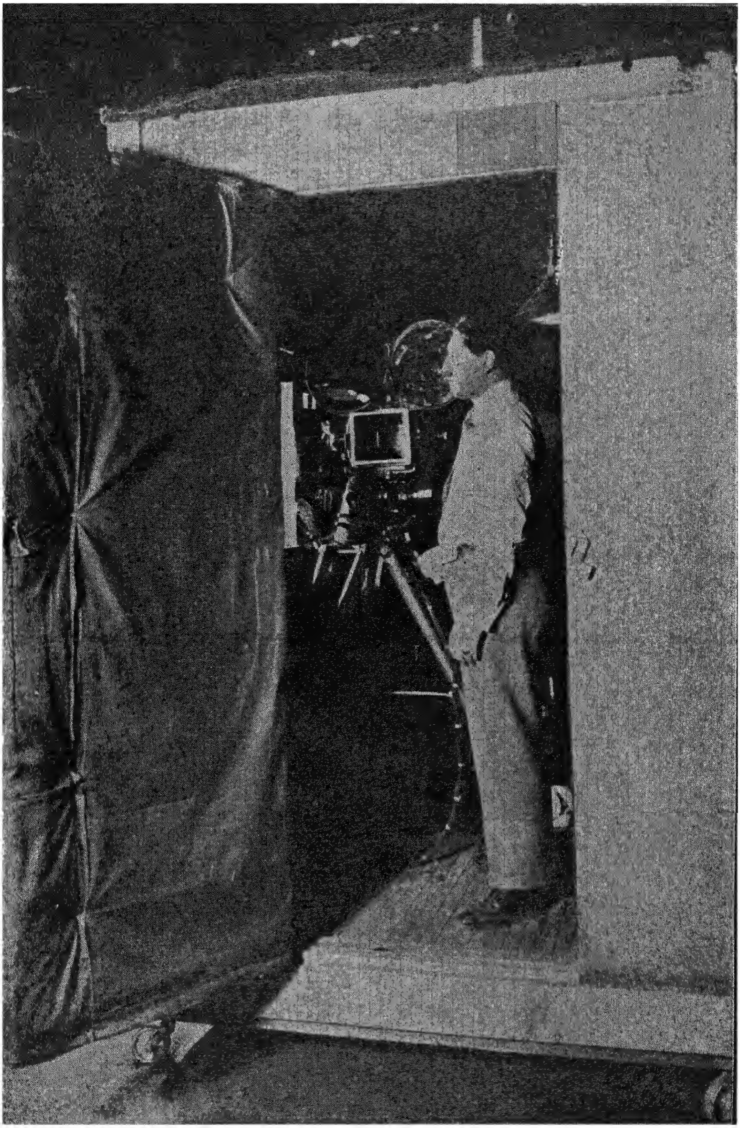


FIG. 96.—A sound-proof camera booth.

The stage is treated acoustically to destroy echoes and excessive reverberation. It is fitted with sound-proof doors, and formerly the cameras were in bulky sound-proof booths, equipped with wheels and double windows;

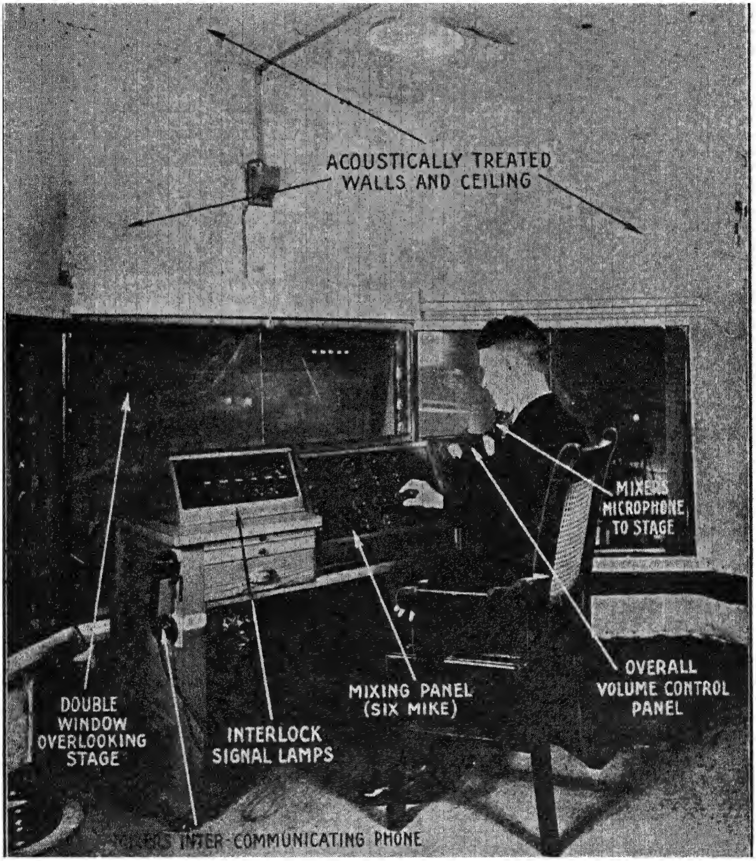


FIG. 97.—The mixer at work.

but now they have been silenced to a point where this is seldom necessary. Klieg (arc) lights are passé; they made too much noise; 1,000-watt incandescents are used. New film has been developed to work with them satisfactorily.

Of course, the "microphones" must be hidden from the eye of the camera, just as the lights and the scaffolding are.

There are from two to six microphones on the average set, and they are swung from booms overhead or camouflaged behind furniture. The next time you tire of watching your show, you can amuse yourself by speculating where the microphones are concealed.

The "Mixer"

Breaking the wall of any stage, half-way up toward the ceiling, the "mixer" window can be seen.

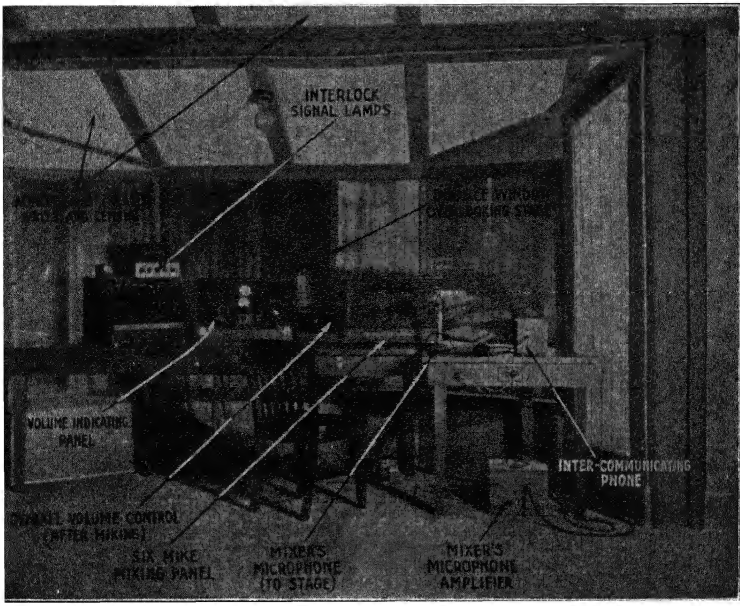


FIG. 98.—Mixer platform, walls and ceiling acoustically treated.

The mixer sits behind this window—double glass, sound-proof—and reads detective stories. The director and cast below him perspire and worry, whipping the "take" into shape. (Their sound-proof box of a stage is often heat-proof, and therefore hot. A few dozen 1,000-watt lamps help to make it hotter.)

When the director is finally ready to record, the scene is rehearsed for the mixer. Microphones concealed from the camera must be within reach of the voice, and, since

there are usually several cameras, and since people move about in movies, placing them correctly is often difficult. That is when the mixer begins his work. He looks down from above, and sees everything. Behind his platform is an acoustically treated room and a regulation theatre loud speaker, through which he hears everything. He has a theatre speaker and his room is sound-treated to enable him to judge quality.

Under his hand are volume controls for the microphones, and one more to govern the overall volume after "mixing." As he listens to the rehearsal, he adjusts the output from each microphone, or mixes, until the result is satisfactory. Beside him is a small microphone of his own, working through a separate low-power amplifier to a little loud speaker which is hung outside his window. With this he speaks to the stage, arranges shifting of the microphones, asks the director to readjust the positions of the players, and so on, to compensate for inequalities in volume that his controls cannot equalize. The director replies by talking into the air. Everything that is said on the stage is heard by the mixer. When everyone is satisfied, the director closes a small switch on his table, thereby indicating that he is ready to "shoot."

That switch lights small colored bulls-eyes on the mixer's table, in the amplifier room, in the recording room, and in the interlock room. One by one the engineers in charge of these rooms turn on switches of their own, each one lighting a tiny lamp on all the other tables, indicating: "We are ready." Every department has a different lamp color assigned to it. When all lights appear before him, the director calls for silence. The great sound-proof doors close; a red bulb flashes outside of them; and the doorman takes up his club and guards that door. One more signal starts the interlock; now all the motors are revolving in synchronism. The final signal is flashed, and shows that the "take" is being "shot."

Lord help the poor devil on that stage who has to sneeze!

The mixer is very busy now, swinging his dials according to the rehearsal. The huge speaker behind his back is telling

him the result. He is listening to the photo-cell in the film recording machine. A pause. The director interrupts. He says: "Cut,"—and, perhaps, other things that will be removed from the record later. Someone runs to the camera with a marked slate which is held up to the lens to record the number of the "take." The director's signal light goes out. One by one other departments turn off their own lights. The motors slow down and stop. The

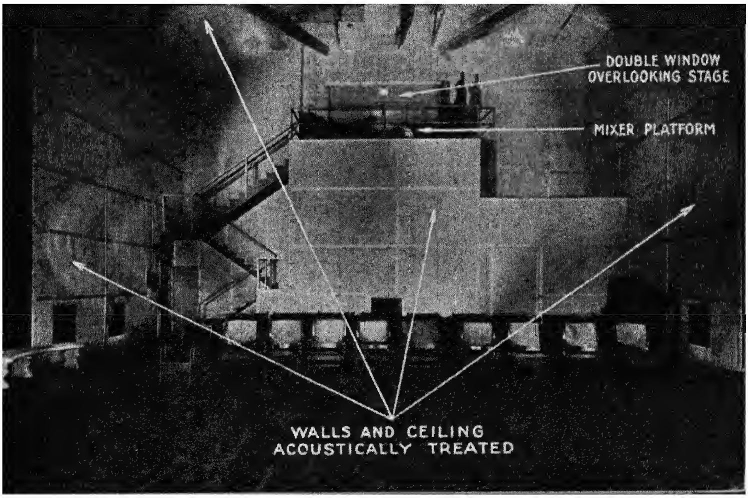


Fig. 99.—Playback room adjoining sound stage, showing mixer platform. The sound stage is a still larger room on the other side of the mixer window. A large horn is hung on the wall of this playback room, directly above the camera which made this photograph.

big doors are opened, and the stifling company gets a breath of air. The "take" is over.

Now comes the "playback." Perhaps there are playback horns on the stage; then the cast will stay to listen. If not, all go into the mixer's room. The playback from soft wax is heard. If everyone is satisfied, that take is history. If not, it is done again.

There are many variations of this general method. Sometimes the director saves the time of a playback by wearing headphones during the take. Sometimes he leaves an assistant in charge and listens and watches from the monitor platform. The signal light arrangement varies in

different studios, and with different systems of recording. Roughly, the process is the same everywhere.

Outdoor recording is another matter. It must be done in a fairly quiet location. For moving scenes the camera and microphones may be mounted on an automobile. Excellent results have been obtained with outdoor recording, but it always involves many factors that are not troublesome in the studio.

In outdoor work all of the equipment is crowded into a truck. It is the same equipment, but every dispensable portion is omitted. The results depend on various conditions; they may or may not be as satisfactory as when studio equipment is used. Many outdoor effects are "faked."

Fooling the Public

Manufacturing sounds to order is the business of every studio. The "effects man" has a laboratory. He can imitate every sound ever heard by man. For example, pistol shots are notoriously hard to record. They "overload" the system. The "effects man" lets his drumstick snap smartly—once—against the head of a snare drum and the recorded illusion will be perfect. He imitates the sound of a ship's foghorn with a tank of compressed air and a contrivance like an organ pipe. He imitates wind by rotating a canvas drum full of walnut shells. Hoofbeats he creats by covering a block of wood in felt, and beating rhythmically upon it with drumsticks; but removing the felt and changing the rhythm reproduces the wheels of a train. He spends his days inventing new effects, and his nights dreaming of them. His is an art in itself.

Effects so recorded, and real sounds too, can be saved and "dubbed on," as explained below, wherever they are needed in the future.

Voices also were commonly imitated in the past. This is not often done today. The method was as follows—a picture was projected a number of times for a man who had a good voice, but was not a screen personality. That man practised until he could sing the song with the picture, timing every slightest motion of the real star's lips.

On some occasions the same method has been tried in reproducing, for export, films which were originally recorded in English. A second cast go over the sound, using the original picture. Timing lip motions was not easy in such a case, and most of the picture would not show the lips of the speakers. For the remaining scenes, the original actors made them again, speaking the foreign language as

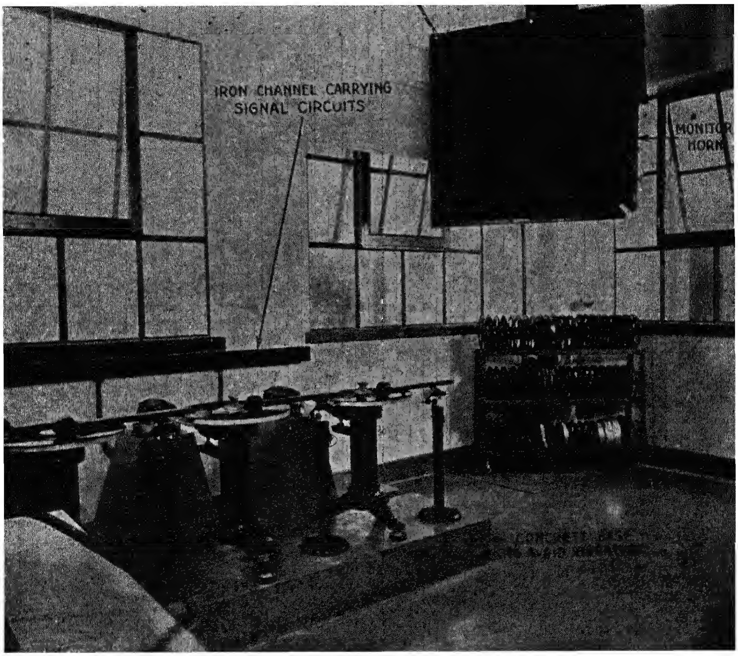


Fig. 100.—A row of disc reproducers, used for dubbing.

best they could after coaching and intent merely on getting the lip movement correct; then the "ghosts" stepped in and furnished the real sound.

Dubbing

"Dubbing," or re-recording, is used extensively in connection with "effects," and also for other purposes. For example, a disc record must play 20 minutes. But some of the scenes on it may be 2 minutes long. It is not practical to record all the takes on one disc, stopping and

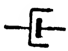
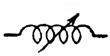
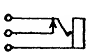
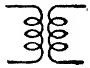
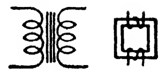
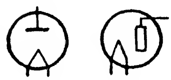
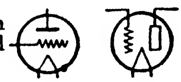
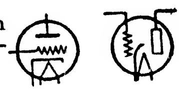
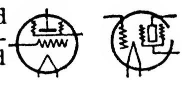
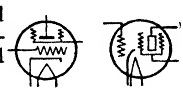
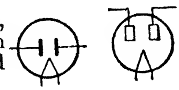
restarting it each time. A new disc is used each time. The finished products are taken to the "dubbing room," where they are played on a row of reproducing turntables, in the ordinary theatre fashion. Switches allow the dubbing engineer to "change" from one disc to the next. He plays these discs in the order desired, re-recording their sound—not through a microphone, but simply by feeding the reproducer output through amplifiers into the recorder. The same can be done with film, but cutting and pasting up film is the easier and better way. Re-recording is not as fashionable as it once was, when directors and executives had a reel dubbed over any time they decided that they preferred to take out some word or sentence. That procedure did not work out very well. Every recording involves some loss of quality; dubbing doubles that loss; dubbing again doubles the double loss, and so on. The process comes to its practicable limit very quickly.

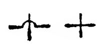
Developing Sound Tracks

Processing and developing sound film is also an art in itself. Especially is this true with sound tracks of the variable density type. To achieve the desired degree of shading in the track, for maximum volume and minimum distortion, requires a definite development; to secure the desired contrast in the picture also requires a definite development, but the two requirements are not the same, and much trouble arose out of this in the early days. Today the problem is overcome for practical purposes by distorting development of both negatives in order to bring them together in a compromise positive that gives perfect results for both.

The early trouble with developing and printing sound-on-film led to the use of two films and two projector heads—one for picture and one for sound. The clumsiness and expense of this method prevented its coming into general favor, and with improvements in processing sound film it was almost entirely discarded. On rare occasions it is still used, and there are those who still claim it yields superior results.

LIST OF SYMBOLS

1. Ammeter 
2. Battery (the positive electrode is indicated by the long line) 
3. Condenser fixed 
4. Condenser, fixed, shielded 
5. Condenser, variable, 
6. Condenser, variable (with moving plate indicated) 
7. Condenser, variable, shielded 
8. Ground 
9. Inductive winding 
10. Inductive winding, adjustable 
11. Inductive winding, iron core 
12. Inductive winding, variable 
13. Jack 
14. Key 
15. Microphone (telephone transmitter) 
16. Photoelectric cell 
17. Resistor 
18. Resistor, adjustable 
19. Telephone receiver 
20. Transformer, air core 
21. Transformer, iron core 
22. Diode (for half-wave rectifier) 
23. Triode (with directly heated cathode) 
24. Triode (with indirectly heated cathode) 
25. Screen-grid tube (with directly heated cathode) 
26. Screen-grid tube (with indirectly heated cathode) 
27. Rectifier tube, full wave (with directly heated cathode) 
28. Voltmeter 

29. Wires, crossed, not joined 

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